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a record of research

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a record of research

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in association with

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HUMAN BIOLOGY

a record of research

FEBRUARY, 1953

VOL. 25 No. 1

A NEW BOARD OF EDITORS

With this issue *Human Biology* appears under a new board of editors, and we take this opportunity to introduce ourselves to our readers—although we realize that you will come to know us best through our work.

Five associate editors have been named. Dr. Josef Brožek of the Laboratory of Physiological Hygiene at the University of Minnesota is known for his studies of the composition of the human body. Dr. Bentley Glass of the Department of Biology at The Johns Hopkins University is interested in genetics and recently has been applying the theoretical concepts of population genetics to data on isolated human groups. Dr. Donald Mainland of the Department of Medical Statistics, New York University, is especially active in the application of bio-statistics to clinical and laboratory investigation in medicine and the study of age changes and of physiological norms. Dr. James N. Spuhler of the Institute of Human Biology at the University of Michigan is trained in anthropology, zoology and human genetics. Dr. Spuhler's research deals particularly with the interaction of social and biological factors in the dynamics of human racial groups. Dr. William L. Straus, Jr., of the Laboratory of Physical Anthropology of The Johns Hopkins University is particularly concerned with the biology of living primates and with human evolution. The editor himself teaches anatomy and is principally interested in anthropology.

As *Human Biology* acquires a new editorial board, we take the opportunity to inform the readers of our goals. Our aim is to represent more fully what our name implies, the intellectual meeting place for students of human biology. While preserving its high traditions, we should like to see this journal grow, more especially in the direction of that kind of human biology which is basic to preventive medicine, physical anthropology and social biology. To do so, we need only keep up with those investigators who are running out in front. It will be our aim to present their contributions to the fields of human genetics, development, growth, reproduction and aging, functional anatomy, bio-anthropology, human ecology and population dynamics.

While our field is *human* biology, we shall not confine our attention narrowly to human life; for to understand that life in all its aspects it is often helpful to observe other forms of life. Just as comparative and experimental studies of various animals have contributed to knowledge of human disease, they can also contribute to knowledge of normal processes in man. Therefore, while it remains our chief purpose to elucidate human biology, we shall, as opportunity affords, also present articles relevant to that purpose in which the subjects of investigation are drawn from other fields.

Lack of a formal society of American human biologists imposes on the editors of *Human Biology* the responsibility of representing all aspects of this vast field of biological science. It also imposes a duty of active participation on the readers. They can help by informing the editors about new projects of research or other matters of professional interest, and by suggesting subjects they would like to see taken up in *Human Biology*. Some have already done so. We wish especially to mention Dr. William W. Howells, the editor of the *American Journal of Physical Anthropology,* who has been very helpful in suggesting suitable articles for publication.

We start our task under auspicious circumstances. A generous grant from the Wenner-Gren Foundation for Anthropological Research will permit us to publish a full volume this year. We take this opportunity to express our gratitude to the Wenner-Gren Foundation. For the future, we place our faith in the continued support of our readers and hope that they will call the attention of their colleagues to the development of our journal.

GABRIEL LASKER
Department of Anatomy
Wayne University College of Medicine

SOME VITAL STATISTICS BASED ON SKELETAL MATERIAL[1]

BY MARCUS S. GOLDSTEIN

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Department of Health, Education, and Welfare, Washington, D. C.

I DO not remember whether I read *The Indians of Pecos Pueblo* voluntarily or under duress as required classroom work, but I did read Professor Hooton's massive contribution ('30), and I was deeply impressed with the sweep of his treatment of the material. Here, it seemed to me, the bones were made to represent living people; their age at death was not merely recorded, but was commented upon; the skeletons were not merely sexed, but sex ratios were considered in their biological-demographic context; and so on. Hence, when I had the privilege some years ago of working up Indian skeletal collections at the University of Texas, I made an attempt to follow the Pecos Pueblo lead, and to answer questions such as: How long did these individuals live? What factors influenced their average length of life? What were the male to female ratios and how might these have affected the survival of the groups? Some evidence pertaining to these questions and comments on their possible implications will be presented below.

The Texas skeletal material came from all the major regions of the state, although most of it was from south, central, and northeast Texas. The skeletons represented peoples living between 800-1700 A. D., according to the University archaeologists (Krieger, '46, and personal communications); most of the material, however, came from pre- or protohistoric horizons.

LENGTH OF LIFE

Estimation of age in the juvenile depended primarily on state of tooth eruption. In the adult, age was judged by degree of tooth wear, epiphyseal union in the skeleton, extent of suture closure in the skull, and general condition of the bones, e. g., vertebral lipping as an indication of old age (Hrdlička, '39).

---

[1] I am grateful to Dr. J. Lawrence Angel for a critical and generously helpful perusal of this paper.

As noted in Table 1, the mean life span, based on age at death, was about 30 years among the Indians living in Texas,[2] compared with a mean of about 43 years for the Pecos Pueblo Indians. It may be noted here that the Texas groups, except those in the northeast, were mainly non-agricultural, in contrast with the agricultural community at Pecos Pueblo. The mean life span of the American Whites at the beginning of the 19th century was apparently also quite short (Table 1). Indeed,

TABLE 1

Mean "life span" of Texas Indians and other groups, both sexes

GROUP	AGE IN YEARS	NUMBER OF INDIVIDUALS
Texas Indians (850-1700 A. D.)	30.5	767
Indians of Pecos Pueblo (800-1700 A. D.)[1]	42.9	587
Ancient Greeks (670 B. C.-600 A. D.)[2]	23.0	544
English (11th century)[3]	35.3	143
Europe, ruling families (1480-1579)[4]	33.7	. .
U. S. White (1800)[5]	30–35	. .
U. S. Negro (1900)[5]	33.8	. .

[1] Calculated from Todd's estimates given by Hooton, '30, p. 19. If the tree-ring dating by Dr. A. E. Douglass, cited by Dr. Hooton, p. 342, is accepted, the time period would be 1100-1700.

[2] Unpublished data generously provided by Dr. J. Lawrence Angel, based on 307 adults, and "younger ages derived from fairly reliable cemetery statistics."

[3] Todd, '27, p. 491.

[4] Peller, '47, p. 82.

[5] Krogman, '40, p. 449; life expectancy from birth.

---

[2] Mean "life span" refers to the arithmetic mean of all ages at death. No allowance was made for loss of skeletons, especially infant material, through disintegration. According to Dr. J. Lawrence Angel (personal communication), in Macedonia at Olynthus only 22% of infant graves had skeletons compared with 80-90% of adult graves having some bone fragments. Assuming that in Texas some 25% of the infant graves (0-4 years) had been recovered, and equating this percentage with an estimated 80% recovery for the remaining ages, some 307 infant skeletons or 31 percent of the total should have been recovered, and the average age at death, all ages, would be reduced to about 24 years. It is of interest in this connection that 30% of all deaths among the Mohave and

the mean age at death of the various groups cited manifests a similarity, with the exception of the Pecos people, which seems to me to suggest that race was not much, if at all, involved in the average number of years lived.

Table 2 gives some idea of the mortality at various age periods in the Texas and other groups. The relatively small representation in the 0–4 years interval in the Texas series is undoubtedly due to the greater likelihood of loss or disintegration of the fragile infant skeleton in the course of time. Too, an unusually large percentage of Texas skeletons falls in the age period 20–34 years. Whether this concentration is due to bias in the estimation of age, or a chance recovery of a disproportionate number of young adult skeletons, or reflects a demographic reality, I do not know. The Texas Indian material is catalogued and stored at the University of Texas and no doubt could be checked for age and other observations. Indeed, the variation among workers in estimating age and sex could, and should, be tested on series of skeletons, preferably of known sex and age at death. These "tests" might be held periodically during meetings of the American Association of Physical Anthropologists.

TABLE 2

Mortality at various age intervals: Texas Indians and other groups[1]

GROUP	AGE AT DEATH (YEARS)						
	ALL AGES	x–3	4–9	10–19	20–34	35–54	55+
	PERCENTAGE DISTRIBUTION						
Early Indian groups in Texas	100.0	12.5[2]	4.7[3]	10.4	29.2	29.6	13.6
Indians of Pecos Pueblo.....	100.0	14.4	7.7	7.7	12.5	39.7	18.4
U. S. Registration Area, 1910	100.0	15.0	2.6	2.4	7.0	15.6	57.5
Italy, males, 1901-1910......	100.0	25.0	3.7	2.8	6.6	12.1	49.8
U. S., Negro males, 1910....	100.0	32.1	4.6	5.1	11.3	17.9	29.1
India, males, 1901-1910......	100.0	39.7	10.1	6.4	12.3	16.8	14.8

[1] All data other than the Texas Indian are from Hooton, '30, p. 25.

[2] Refers to ages 0–4 years.

[3] Refers to ages 5–9 years.

Chemehuevi Indians of western Arizona between 1910-1930 were in the age group 0–4 years; the calculated mean age at death was 32 years (Clements, '31, p. 398).

To return to Table 2, it may be noted that relatively few individuals apparently lived beyond middle age in either the early Indian groups of Texas or at the Pecos Pueblo (14% and 18%, respectively). Interestingly, just about the same proportion of people reached old age in England in the middle ages, or for that matter, in recent times in India.

Sex. Unlike the present longer life span of the female, the males apparently lived longer on the average than the females among the early Texas Indian groups and ancient Greeks (Table 3). The relatively much larger number of female skeletons than males adjudged 18–34 years of age at death very likely reflects the high maternal death rate at childbirth which must have prevailed at the time.

TABLE 3

Age at death, by sex: Texas Indians and Ancient Greeks[1]

GROUP	NUMBER OF INDIVIDUALS	MEAN AGE (YEARS)	PERCENTAGE DISTRIBUTION AT AGES			
			18–19	20–34	35–54	55+
Texas Indians						
Males	270	41.0	2.6	25.2	45.9	26.3
Females	237	33.9	5.5	48.1	35.0	11.4
Ancient Greeks[2]						
Males	249	39.8	0.8	39.4	54.6	5.2
Females	135	31.0	14.1	63.0	22.2	0.7

[1] All ages under 18 years are excluded in order to attain greater reliability of the sex determinations.

[2] Angel, '47, p. 20.

Locality. Was there any difference in mean life span among the various Texas Indian groups represented by skeletal remains? To answer this question, the material was divided by regions roughly approximating archaeological divisions in the State.[3] Table 4 gives the results.

---

[3] Northeast Texas or "Caddo Area" includes the Sanders Focus and Texarkana Focus; North Texas, the Henrietta Focus and Antelope Creek Focus (Texas Panhandle); Central Texas, the Edwards Plateau Culture; West, in the present instance, refers almost altogether to remains of cave-dwellers (see Krieger, '46).

Fairly good series of skeletons were available from three sites, and age at death of the people at these places is shown in Table 5. The Sanders site in northeast Texas refers to a period circa 1300-1400 and revealed the practice of agriculture and a relatively advanced culture (Krieger, '46). The Oso and Morhiss sites in south Texas were pre-Columbian and showed no sign of the practice of agriculture. Rather

TABLE 4

Mean age at death of Texas Indians, by location

LOCALITY	BOTH SEXES [1]		MALES [2]		FEMALES [2]	
	Number	Age	Number	Age	Number	Age
North (1250-1450)	63	34.8	33	41.1	20	32.7
South (——-1700)	285	30.5	89	41.4	103	31.2
Northeast (1300-1600)	227	30.3	70	40.6	76	33.4
Central (850-1450)	144	29.6	56	41.1	30	44.9
West (900-1300)	48	28.5	22	40.9	8	34.2
Total	767	30.5	270	41.0	237	33.9
S. D.		18.5				

[1] The number of cases in both sexes as compared with the combined number of males and females differs by the number of cases under 18 years of age, sex of which in most cases could not be determined with reasonable certainty.

[2] Includes cases 18 years of age and over only.

TABLE 5

Mean age at death of Indians at three localities in Texas as estimated from their remains, both sexes

GROUP	ALL AGES		ADULTS ONLY				
					Percentage at ages		
	Number	Mean age	Number	Mean age	18–34	35–54	55+
Sanders site (northeast Texas)..	69	37	51	42	27.5	43.1	29.4
Morhiss mound (south Texas)......	98	31	58	36	44.8	34.5	20.7
Oso site (south Texas)..	68	27	46	34	60.9	21.7	17.4

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substantial differences are noted between the mean age at death among these several groups, especially between the Sanders and Oso peoples.[4]

European Contact. The material has been further divided according to archaeological manifestation of European contact. European contact in the present instance almost altogether means merely association with European artifacts. Direct and extensive white contact among the groups represented by their skeletal remains occurred perhaps only in the case of the mission Indians of south Texas, whose remains comprise a very small proportion of the total examined. In any case, the mean age at death of 55 individuals from sites showing European contact was 40 years, and of 290 individuals manifesting no such association, 36 years.[5] The difference between the means is not statistically significant at the 5% level of probability.

Agriculture and Length of Life. A test was made of the hypothesis that the practice of agriculture by a group—presumably indicative of a more sedentary existence and stable economy than among groups not practicing agriculture—was conducive to longer life than in primarily hunting or fishing cultures. The mean age of all the material from sites showing definite signs of the use of agriculture (104 individuals) was 39 years; that of the non-agricultural group (241 individuals) was 35 years. Unexpectedly, the difference between the means in this instance is not significant at the 5% level of probability.

SEX RATIOS

A few comments may be made on the ratios of males per 100 females as found in the Texas remains and in other groups. Although the Texas Indian data on sex given in Table 6 are not strictly comparable with Professor Hooton's Pecos Pueblo figures or those from the U. S. Census, since sex was estimated beginning at 10 years of age in the Pecos material and was recorded at all ages in the Census, it is of interest that the Texas Indian ratio of 112.6 is quite similar to both the Tanoan and Mexican male to female ratios. The total living Indian population in the United States in 1930 also manifested a higher ratio of males to females, but only slightly more so than in the United States whites at this time.

---

[4] Ages at death for all the skeletons observed at these sites were not available to me when this paper was written, and hence the statistical significance of the differences between the means could not be calculated. However, the chi-square may be computed from the distributions given for the adults; only the Sanders compared with the Oso data showed a chi-square that was significant at the 5% level of probability.

[5] The age data relating to European contact are based on skulls only, and hence the smaller number of total individuals than in the previous counts.

Age apparently has a considerable influence on the sex ratios. In the Texas material and also in the Pecos remains, as well as for the cited living Indians groups, females definitely outnumbered the males in the early years, but in turn were outnumbered in the middle years and especially in old age, one more indication of longer life among the males.

TABLE 6

Ratio of males per 100 females in Texas Indians and in other groups [1]

	MALES TO 100 FEMALES BY AGE				
	Total		18–34* Under 20**	35–54* 20–50**	55+* 51+**
GROUP	No.	Ratio	Ratio	Ratio	Ratio
Skeletons					
Texas Indian [2]	536	112.6	57.2*	141.3*	272.4*
Pecos Pueblo	667	140.8	70.9**	150.8**	146.2**
Living					
Jemez Indians (1910)	499	128.9	104.7**	152.8**	142.3**
All Tanoan Indians (1910)	3,137	108.7	92.4**	120.6**	136.2**
U. S. Indian (1930)	..	105.1	..	..	..
U. S. Mexican (1930)	..	114.3	..	..	..
U. S. White (1930)	..	102.7	..	..	..
U. S. Negro (1930)	..	97.0	..	..	..

[1] The Pecos, Jemez, and Tanoan groups are from Hooton, '30, p. 31; the 1930 data are from the 15th Census of the United States, Summary, p. 8.

[2] Includes 29 cases from Stewart, '35, p. 215.

A pertinent passage of Professor Hooton's on the sex ratio may well be given in full ('30, p. 31):

"I have been inclined to attribute the great excess of males in skeletal population to the better weathering of male skeletons or to a possible tendency of the laboratory worker to assign to the male sex skeletons of masculine appearance which were in reality females. However, the comparison of the Pecos skeletal population with the sex ratios in living peoples of the same stock indicates that the great excess of males should not be attributed to any such source of error.

"In a population which is remaining stationary or declining in numbers one expects the number of males to exceed markedly the number of females. This excess of males is usually attributable to an actual difference of the proportions of the sexes at birth. We need not here discuss the hypothesis of the relation of nutritional factors to sex determination, but it may be remarked that if, as some think, a well nourished and increasing population produces an excess of females at birth, whereas a badly nourished and declining population produces an excess of males at birth, we may well expect the population of the extinct Pecos pueblo to manifest in a high degree the latter type of disproportion of the sexes."

That a badly nourished people necessarily is a declining population would seem rather dubious in view of the examples of China and India, countries in which malnutrition is notoriously common and yet, so far as I am aware, they suffer from no lack of fecundity. The other point raised, that an excessive proportion of males over females is indicative of a stationary or declining population, seems to me provocative and should be explored further. What conditions induce such a disproportion in the sexes in present populations? What might they have been among early Indian groups?

In my closing remarks I would like to suggest that length of life was and is affected as much or more by the culture of a group and its neighbors as by the biological or genetic constitution of its members. Variations in the potential life span of individuals very likely do occur. Yet, as suggested by the Pecos Pueblo material, a cultural artifact, agriculture, or the more secure mode of living implied by an economy dependent on or considerably supplemented by agriculture, apparently had a significant influence on length of life, and probably also on the chance of initial survival. The risk of accidental deaths must have been much greater among nomadic than among sedentary groups.

A striking example is given by Kroeber ('39, p. 148) of the effects of a social custom on the very existence of the eastern American Indians. Thus, their "warlike habits [were] so integrated into the whole fabric of Eastern culture, so dominantly emphasized within it, that escape from it was well-nigh impossible. This warfare, with its attendant unsettlement, confusion, destruction, and famines, was probably the most potent reason why population remained low in the East."

The late Professor Wingate Todd, also commenting on the subject, stated ('27, p. 496):

"The difference between the peaks of mortality in primitive and ancient people on the one hand and of modern civilized humanity on the other is roughly thirty years. This difference does not indicate a prolongation of the potential duration of life which undoubtedly remains stationary through the ages. In modern populations, even in civilized communities, drawn from the lower strata of society, the old age peak characteristic of today is not to be found, owing to the relatively great hazards of life to which these unfortunate people are exposed when not sheltered by specific social legislation."

Some have suggested on the basis of life expectancy curves from epigraphic data and skeletal remains, and an assumed "rigorous selection at earlier ages," that persons in ancient times may have had a longer life expectancy after reaching old age (i. e., life expectancy at age 65 or thereabout) than is the case at present even in a country like England or the United States (Pearson, '01; Macdonell, '13; Angel, '47). Be this as it may, it should be clear that large numbers of people living to old age (65 years and over), as distinct from continued life span of individuals in the old-age brackets, is a very recent phenomenon, probably limited to countries and groups in which the infant and child mortality rates are low and modern public health and medical care services are generally available.[6]

SUMMARY

Mean age at death of Indians living within the present bounds of Texas, for the most part in pre- and protohistoric times, is estimated as about 30.5 years on the basis of examination of 767 of their skeletons. When account is taken of a high rate of nonrecovery of infant skeletons, the average age at death is reduced to about 24 years. Mortality at different age periods is noted; a large percentage of deaths apparently occurred in the age period 20–34 years. Relatively few individuals (14%) lived beyond middle age. Males seemingly lived longer than females. Variation in mean age at death among groups located in different parts of the State is indicated. Considering adult skeletons only (18 years and over) the male to female ratio was 112.6. The implication of cultural factors on length of life is discussed.

---

[6] In the United States, for example, the infant mortality rate (deaths under 1 year per 1,000 live births, for birth registration States) decreased from 85.8 in 1920 to 31.3 in 1949; and according to the censuses, the percentage of the population aged 65 and over was 2.9 in 1870; 4.1 in 1900; 4.7 in 1920; and 8.2 in 1950.

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BIRTH INTERVAL AND BODY SIZE

BY W. W. HOWELLS

University of Wisconsin [1]

IN connection with a study of body size and birth order, the writer (1) examined certain other family characteristics in relation to body size, one of them being birth interval. There were found preliminary indications that those whose births had followed relatively soon after that of the next oldest sibling were shorter on the average in adult stature. Such a possibility would not be unreasonable, on the hypothesis that a new pregnancy in the immediate post-partum period might find that mother's reproductive system not fully restored to "normal." Yerushalmy (4) found evidence that stillbirth rates were higher for the shortest (and also the longest) birth intervals, and cited previous work which had, by methods different from his, demonstrated the same effect.

Whether this influence might also have an effect on post-natal development is another matter. Such a factor, if actual, might be a significant non-genetic cause of familial variation: it might, for example, explain the slight, and statistically unreliable, tendency found by the writer, in the study cited above, for older brothers to exceed younger brothers in stature, particularly, by the argument that elder brothers would include a proportion of first births (as younger brothers would not) who thus could not have been exposed to the hazard suggested: a less favorable pre-natal environment due to the demands made upon the reproductive tract by a very recent occupant of it.

At any rate suggestions were found, as has been said, in the brother material of smaller stature for short birth intervals. However, the material was then in improper form for study of the question, and an

---

[1] This study was supported by the Research Committee of the Graduate School, from special funds voted by the Wisconsin State Legislature. Measuring or computation involved was performed at various times by Earle L. Reynolds T. W. McKern, R. L. Hornseth, N. C. Tappen and R. F. Maher.

analysis was tried on another series, of Short Course students, entirely of Wisconsin farm extraction, measured in 1942. In this case, analysis of variance showed that the distribution of stature by "interval to previous birth" was abnormal, the abnormality (excess of between-group variance) being significant at the 1% level; also, those with the shortest interval to previous birth (1 year) were significantly shorter in stature than the total group. Here also, however, the groupings were unsuitably coarse (birth interval being reckoned in round years, from the ages of the subjects), and consequently the results are not reproduced. Nevertheless this indicated further work along the same lines with birth interval reckoned more precisely, i. e. in months. This impression was sustained by later preliminary runoffs of results, shown in Table 1;

TABLE 1

Relation of stature and birth interval. Moving averages, 4-month groupings

INTERVAL TO PREVIOUS BIRTH IN MONTHS	STATURE MEANS	
	UNIVERSITY STUDENTS, 1947	SHORT COURSE STUDENTS, 1947
10	168. (1)	187. (1)
10–11	168. (1)	187. (1)
10–12	173.00 (3)	187. (1)
10–13	174.40 (5)	173.62 (8)
11–14	172.00 (12)	170.73 (11)
12–15	173.47 (15)	170.73 (11)
13–16	173.21 (19)	171.70 (17)
14–17	173.04 (22)	171.54 (11)
15–18	175.33 (18)	174.09 (11)
16–19	175.00 (18)	174.67 (12)
17–20	176.48 (23)	175.62 (13)
18–21	177.52 (21)	176.50 (14)
19–22	177.30 (23)	176.91 (11)
20–23	177.30 (20)	174.31 (13)
21–24	177.00 (10)	173.00 (6)
22–25	175.75 (8)	171.67 (6)
23–26	176.43 (7)	168.43 (7)
24–27	176.08 (12)	171.40 (5)
25–28	176.94 (16)	172.83 (6)
26–29	176.70 (17)	173.43 (7)
27–30	176.30 (13)	177.00 (9)

these, based on the small numbers of subjects available, indicated that a division at 18 months would be a reasonable one for the analysis of the rest of the material, and that, because of the small numbers, groupings had best consist of: first-born, interval x-18 months, and interval 19-x months, without further subdivision.

Means according to these groupings for all measurements were run off for four separate series, three of them being Short Course student groups measured in different years (composed entirely of Wisconsin farm-living young men) and one being a series of University students from urban, non-farm homes.[2] The results were negative; i. e. there was no general, reliable indication of differences in body form as between those characterized by short intervals to previous births, and those characterized by longer intervals, or first-born. It is believed that the results should be reported anyway, for the benefit of those interested in problems of possible non-genetic effects on physique.

These results are given in Table 2. In view of the lack of positive

TABLE 2

Short Course Students, 1942

	FIRST BORN	INTERVAL TO PREVIOUS BIRTH	
		x-18 MOS.	19-x MOS.
NUMBER	31	11	42
Stature	176.00	174.27	175.00
Sitting height	92.06	91.64	91.40
Total arm length	78.06	77.73	77.57
Length of radius	268.16	261.18	264.14
Length of tibia	396.58	395.00	394.17
Biacromial	398.48	397.36	395.52
Biiliac	307.68	300.55	302.60
Head circumference	568.42	558.09	566.40
Head length	196.81	192.73	195.48
Head breadth	153.52	150.82	152.43
Minimum frontal	105.65	104.64	104.57
Bizygomatic	137.94	139.27	136.86
Bigonial	108.00	109.73	106.14
Face height	132.10	128.36	130.71
Upper face height	82.00	80.64	80.51
Nose height	63.16	61.55	62.49
Nose breadth	35.32	36.64	36.24

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[2] This material was originally obtained by T. W. McKern (3), to whom I am obliged for permission to use it for the present purpose.

TABLE 2 (Continued)

Short Course Students, 1947

	FIRST BORN	INTERVAL TO PREVIOUS BIRTH	
		x-18 MOS.	19-x MOS.
NUMBER	15	17	40
Stature	171.20	174.00	175.92
Sitting height	88.87	90.71	91.50
Total arm length	78.27	80.47	79.73
Length of radius	261.73	257.29	262.68
Length of tibia	374.27	386.47	390.20
Biacromial	396.47	395.71	394.10
Biiliac	287.87	299.18	300.48
Head circumference	561.33	567.06	567.03
Head length	191.47	191.47	193.93
Head breadth	152.00	153.12	153.48
Minimum frontal	103.33	102.59	104.20
Bizygomatic	137.60	138.35	138.90
Bigonial	108.53	108.00	109.38
Face height	127.73	124.65	129.18
Upper face height	78.67	75.29	77.45
Nose height	58.73	57.06	58.78
Nose breadth	35.13	34.29	35.75

TABLE 2 (Continued)

Short Course Students, 1948

	FIRST BORN	INTERVAL TO PREVIOUS BIRTH	
		x-18 MOS.	19-x MOS.
NUMBER	27	14	66
Stature	175.19	171.21	173.59
Sitting height	92.00	89.14	91.08
Total arm length	78.52	76.93	78.06
Length of radius	262.74	266.07	258.95
Length of tibia	394.96	390.36	389.74
Biacromial	409.22	416.36	408.92
Biiliac	292.37	289.29	291.30
Head circumference	567.89	564.14	564.74
Head length	193.30	192.14	193.20
Head breadth	153.26	153.43	152.77
Minimum frontal	103.00	101.57	102.21
Bizygomatic	138.59	138.36	138.32
Bigonial	105.07	104.57	104.91
Face height	126.70	127.57	125.35
Upper face height	76.37	78.21	75.30
Nose height	58.26	59.57	57.62
Nose breadth	35.07	34.67	35.26

TABLE 2 (Continued)

University Students, 1947

	FIRST BORN	INTERVAL TO PREVIOUS BIRTH	
		x-18 MOS.	19-x MOS.
NUMBER	85	31	99
Stature	175.95	173.81	176.46
Sitting height	91.32	90.58	91.56
Total arm length	77.31	77.80	78.29
Length of radius	256.11	254.55	253.72
Length of tibia	394.06	392.19	394.40
Biacromial	409.50	409.71	407.03
Head circumference	569.05	568.61	569.43
Head length	194.09	195.19	194.39
Head breadth	153.60	153.39	154.23
Minimum frontal	105.65	105.13	106.11
Bizygomatic	139.09	139.58	138.55
Bigonal	106.53	107.07	106.42
Face height	130.47	129.10	130.19
Upper face height	78.96	77.90	79.09
Nose height	61.24	59.65	61.47
Nose breadth	38.45	38.87	38.29

trends it is clearly unnecessary to carry out extensive tests of significance of differences, and only the means are given. A larger single series might have been obtained by combining the three Short Course series, whose background is essentially identical except for year of attendance; however, analysis of variance in several measurements showed that this could not be properly done; the groups cannot be accepted as samplings from the same universe, in this case obviously because of differences in measuring technique, the three series having been measured by two different observers.

Stature was the measurement of which the behavior in preliminary work led to the full investigation, and it is stature alone which shows a good degree of consistency throughout in favor of longer birth intervals. The only other measurements even suggesting such a trend are sitting height (certainly not limb lengths), head circumference, and possibly heights of the face. Perhaps shoulder breadth is consistent in an opposite trend, along with head breadth or minimum frontal. However, the suspicion is that all the variation is meaningless. Even in the greatest stature difference, in the University 1947 series, the long-interval group exceeds the short-interval group by an amount significant only at the 5% level according to the t test; however, analysis of variance indicates that the whole distribution of stature in this series is probably not abnormal, indicating that this difference should be disregarded.

In Table 3 a further comparison is made, this one consisting of

TABLE 3

Mean differences, in millimeters, between contiguous pairs of brothers, all birth orders, according to interval between their births. (Plus values favor elder brothers).

	INTERVAL BETWEEN BIRTHS			
	x-18 MOS.		19-x MOS.	
Stature	19.40	(25)	1.20	(49)
Sitting height	6.31	(26)	3.86	(50)
Upper arm length	—.42	(26)	2.70	(50)
Lower arm length	2.15	(26)	.75	(51)
Lower leg length	—.96	(25)	—2.22	(49)
Biacromial	.96	(26)	2.76	(51)
Biiliac	.42	(26)	2.49	(51)
Head circumference	5.69	(26)	—1.68	(50)
Head length	2.19	(26)	— .21	(51)
Head breadth	1.04	(26)	— .12	(51)
Head height	—.23	(26)	—1.29	(51)
Minimum frontal	.77	(26)	— .98	(51)
Bizygomatic	1.38	(26)	1.08	(51)
Bigonial	.38	(26)	1.37	(51)
Face height	—.23	(26)	.61	(51)
Upper face height	—.62	(26)	.39	(51)
Nose height	.31	(26)	— .14	(51)
Nose breadth	—.54	(26)	.24	(50)
Ear length	.27	(26)	1.18	(51)
Ear breadth	—.58	(26)	— .51	(51)

actual differences between pairs of brothers (from Howells, 1, 2) according to birth interval. This has a complicating factor, since the older brothers are partly first births, and partly those who may have had a short interval to previous birth themselves. There is no indication of general trend, or of significant differences, in this material; however, stature follows the same trend, and biacromial breadth likewise follows the opposite trend. Nevertheless, the whole investigation cannot be accepted as demonstrating that interval to previous birth has an effect on physical development of the adult.

While this material was in preparation, and before the results were known, it was decided to look into another possible biological result of variation in birth interval: whether post-natal mortality, like the still-birth rate, might be influenced by this pre-natal factor. To get a population not under the influence of birth control (in its present overt form), and in which death had overtaken everyone, material was taken from the published Vital Records of Massachusetts towns, which list recorded births, marriages and deaths up to 1850 (and are apparently fairly complete in their listings of infant and juvenile deaths). The manner of searching this material—having to find both birth and death dates of an individual—imposes at least two biases, neither of them unfavorable: the individuals concerned lived in the same town or nearby throughout life; and large families were necessarily selected, to give a better chance of finding both birth interval and death date for the same individual. First births are derived from the same families. Naturally, even with plentiful records, it is not too easy to make up a large sample of data; the 177 used were found without too great an expenditure of time, however, and were considered adequate for purposes of a test.

TABLE 4

Birth interval and length of life. Data from Vital Records of Massachusetts towns; deaths prior to 1850. (Expected frequencies in italics).

INTERVAL TO PREVIOUS BIRTH	AGE AT DEATH 0–20	20–50	50–x	TOTAL
First born	10 *10.76*	11 *9.49*	7 *7.75*	28
0–20 mos.	15 *18.44*	21 *16.27*	12 *13.29*	48
21–30 mos.	25 *25.74*	19 *22.71*	23 *18.54*	67
31–x mos.	18 *13.06*	9 *11.53*	7 *9.41*	34
Total	68	60	49	177

$\chi^2 = 7.24$
degrees of freedom = 6
$P = .30$

The result is shown in Table 4. This constitutes the most favorable arrangement of the data for the hypothesis under scrutiny. It is evident that no support for the hypothesis appears. Even though the numbers are small, there is no encouragement to try a broader survey of the same kind.

The tests described in this paper are not only based on small numbers but are relatively crude, since other possible influencing factors, such as family size, age of mother, etc., cannot be isolated or held constant without more material.[3] The hypothesis, however, would appear to be discredited. Possibly the influence reported by Yerushalmy and others may have a selective effect, by tending to eliminate through stillbirth those suffering the handicap of a short interval to previous birth, or at least in this way reducing the residual effect of such a factor to a minimum. It would take a considerably wider study than the present one to discover if this is so.

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[3] Several such factors were investigated individually by using part of the material; none of them was found to have a discernible gross effect on stature. These factors were age of subject, age of mother at subject's birth, family size, and birth order. See also Howells (1).

THE DETERMINATION OF THE SEX OF SKELETONS, AS ILLUSTRATED BY A STUDY OF THE ESKIMO PELVIS

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THE purpose of this paper is to present a method of determining the sex of skeletons, which avoids the necessity of the investigator making subjective judgments. Not only are such determinations important in medico-legal cases but they are the first step in the study of archeological remains. In spite of the importance of this problem, there appears to be no objective method of ascertaining the sex, even of the pelvis. It has been standard procedure on the part of anthropologists in this country to sort skeletons of unknown sex into males and females and then to treat these groups separately. Clearly the sexual differentiation described in this way is dependent to an unknown extent on the biases of the person making the original decisions. If there were very few cases of doubtful sex, this might not be a matter of practical concern, but Howells ('41) estimates that there may be disagreement among experts in 15% of cases, and this is more than enough to cause major difficulty in the study of race, sex, and variability of prehistoric populations.

Studies on pelves of known sex from anatomical laboratories have shown that the pubic bone is relatively longer in the female and that the sex of the majority of pelves can be determined by the relative length of the ischium and the pubis (Washburn, '48, '49). However, these studies also show that there are racial differences in this index, just as there are in all other skeletal indicators of sex. Because of this variation it is not possible to apply the standards of samples of known sex to new series from widely varying times and places. Krukierek ('51) has shown that the form of the pelvis is affected by environment

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(probably diet) and so standards must be applied with caution, even within the same racial group.

What is needed is a quantitative method which will divide a series automatically into those probably male and those probably female and which will allow some estimate of the error. To be useful the method must work, even if the degree of sexual differentiation in the new sample is somewhat different from that of any group previously investigated. It may be assumed that the sexual differentiation in the new series will be of the same general nature as that in samples of known sex, but the means and variabilities may well be different.

Since previous studies have described differences between American Whites and Negroes (Straus, '27 and Washburn, '48) and Bantu (Washburn, '49), Mongoloids were selected for this investigation. Through the generosity of Dr. T. D. Stewart it was possible for Hanna to study the extensive collection of Eskimo skeletons in the U. S. National Museum. We are grateful to Dr. Stewart for his help and advice. We wish to thank the Wenner-Gren Foundation for Anthropological Research whose financial support made this study possibles.

Material and methods. The series investigated consists of 224 skeletons of Eskimos from Alaska. No known Indians or Aleuts are included. The length of pubis, ischium, upper ilium, and lower ilium, and angle of the sciatic notch were measured on 224 right innominate bones. All were adult, judging by the pubic symphysis. Length of pubis and ischium were measured according to the technique described by Schultz ('30). In measuring the iliac heights the technique described by Straus ('27) was followed. The angle of the sciatic notch was determined by: placing the innominate bone, medial surface upward, on a piece of paper; tracing the shadow of the notch cast by a single, distant light; and drawing straight lines tangent to the sides of the notch. The angle between the lines was measured, and both the tracing and measurement were checked against the innominate bone to make sure that there had been no distortion. All the measurements were taken by Hanna.

Various methods of sorting the data were tried and the most effective is shown in Figure 1. If the ischium-pubis index is plotted on one axis and the angle of the sciatic notch on the other, the data are sorted into two distributions which are almost completely separate. After considering, in addition, the interiliac index and gross size, the two groups were divided, as shown by the line in Figure 1. Using this division, the mean, range and standard deviation of each measurement and index was calculated, and the result are shown in Table 1. The correlations of the measurements and indices are shown in Table 2.

TABLE 1

Measurements and Indices of 95 "female" and 129 "male" Eskimo

	"FEMALE"				"MALE"			
	Mean	Range	S. D.	C. V.	Mean	Range	S. D.	C. V.
Pubis length, mm.	80.1	(73-90)	5.1	6.3	74.1	(63-85)	4.0	5.3
Ischium length, mm.	81.0	(72-89)	5.0	6.1	88.4	(79-98)	4.0	4.5
Ischium-Pubis Index, %	98.8	(91-109)	3.8	3.8	83.9	(73-92)	3.7	4.4
Sciatic Notch Angle, degrees	74.4	(61-93)	7.1	9.5	50.4	(26-65)	8.4	16.6
Upper Iliac Height, mm.	64.2	(50-76)	5.4	8.4	72.4	(61-85)	5.2	7.2
Lower Iliac Height, mm.	61.8	(54-77)	6.9	11.1	54.5	(42-67)	5.4	9.9
Interiliac Index, %	104.5	(73-140)	14.1	13.4	133.6	(100-177)	15.9	11.9

TABLE 2

Coefficients of Correlation

	"MALE"	"FEMALE"
Ischium-pubis Index and Angle of Sciatic Notch	+ .32	— .10
Ischium-pubis Index and Interiliac Index	— .08	+ .01
Pubis length and Lower Iliac height	— .06	+ .17
Ischium length and Upper Iliac height	+ .40	+ .37

Discussion. On the basis of the combination of the ischium-pubis index, the angle of the sciatic notch, the interiliac index, and gross size, the Eskimo innominate bones were divided into two groups, as shown in Figures 1 and 2. One group is characterized by high ischium-pubis indices, wide sciatic notches, low interiliac indices, and small size.

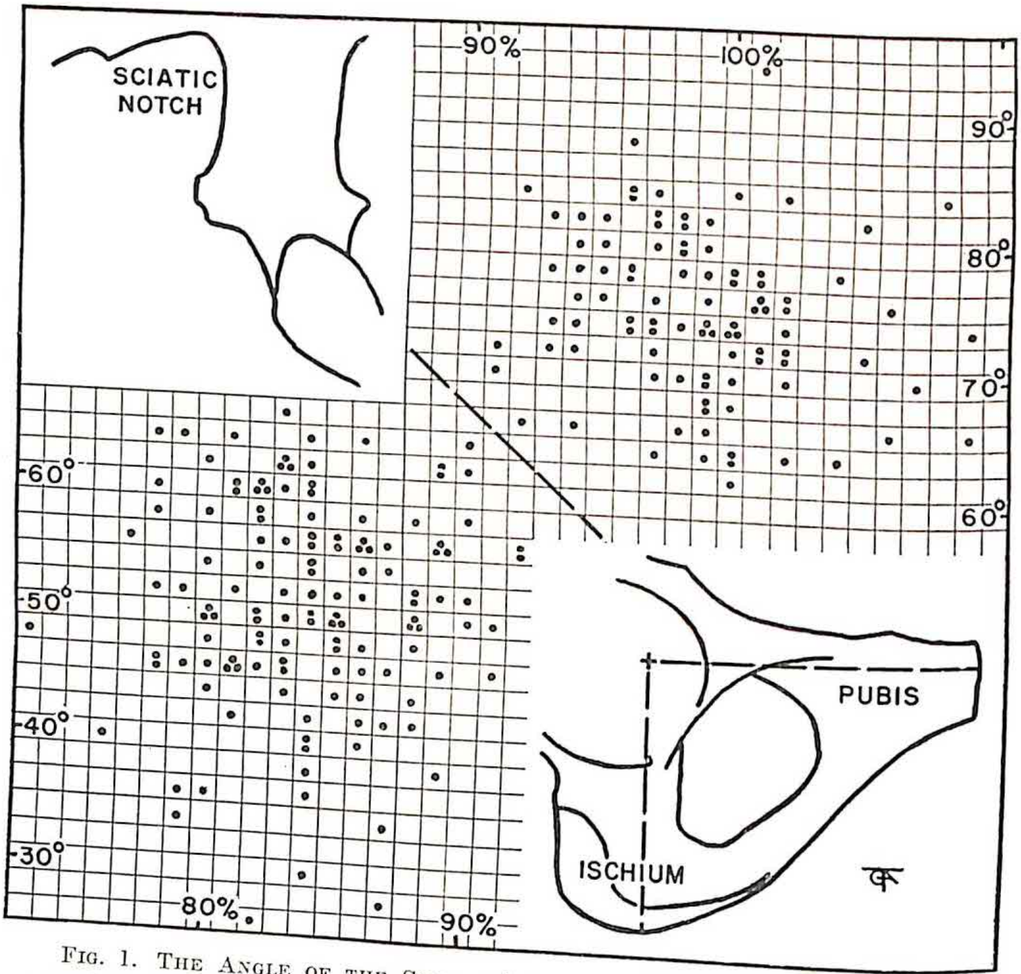

Fig. 1. The Angle of the Sciatic Notch in Degrees Plotted Against the Ischium-Pubis Index in Per Cent. Diagonal Line Separates "Males" and "Females."

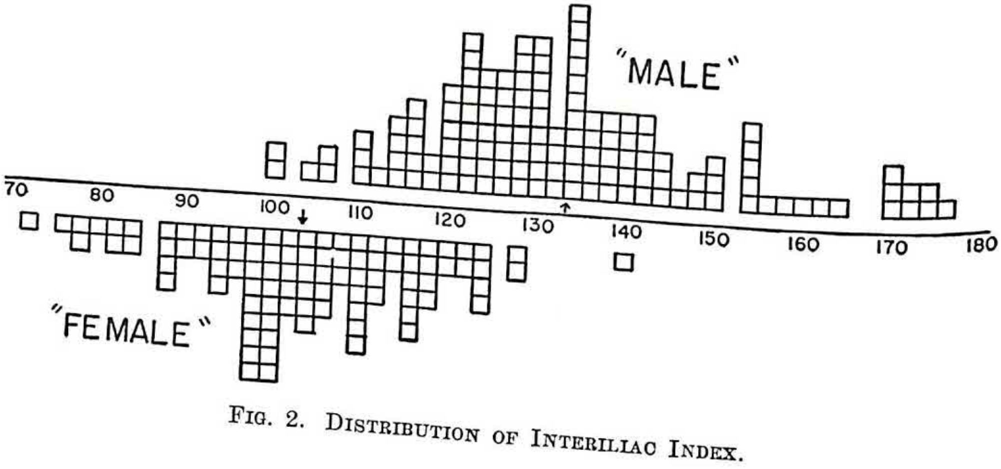

Fig. 2. Distribution of Interiliac Index.

Investigations of pelves of known sex have shown that these are the characteristics of females (Straus, '27 and Washburn, '48, '49). Conversely, the traits of the other group are those of males. The ischium-pubis indices of these Eskimo are almost identical with those of Whites of known sex from anatomical laboratories (White male, 83.6%, Eskimo, 83.9%; White female, 99.5%, Eskimo, 98.8%). There are very few cases which are intermediate in character, and, even the sorting shown in Figure 1, which is based only on the ischium-pubis index and the sciatic notch, separates over 95% of the total series into two very distinct groups. There is no indication of 15% of skeletons of uncertain sex, as has been suggested in the literature (Howells, '41, Hooton, '46).

Although most of the determinations of sex seem to be correct, there are some marginal cases, and these need to be considered in more detail to judge the effectiveness of the method. In considering the probability of the assignment of sex in any individual case, the consistency of the traits should be emphasized. There are no cases at all in which extreme male features are combined with female characters. For example, in the whole series there are many specimens with narrow sciatic notches and many with high ischium-pubis indices, but in no single case is an angle of over 70 degrees combined with an index of less than 90%. Conversely, a notch of less than 60 degrees is never combined with an index of over 92%. An interiliac index of over 140% never is associated with a wide notch or high ischium-pubis index, while interiliac indices of less than 100% only occur in combination with wide notches and high ischium-pubis indices. In other word, there are *no cases* in which a trait which is clearly male or female is combined with a character of the opposite sex. This method of sorting stresses the certainty at the extremes, rather than the probability computed from the averages. On the basis of series of known sex, and the combinations of traits in this series, there is no reason to suppose that extremely male traits ever occur in combination with extremely female traits, (barring pathology or very rare anomalies). Innominate bones whose sex can not be determined with certainty will be ones which are intermediate in all the characters used in sorting. In this series the borderline cases will have ischium-pubis indices between 90-92%, combined with angles of 60-70° and interiliac indices of 100-140%, with ischia 80-90 mm. long. There are only 2 such individuals in 224 cases.

Since there are very few errors in the assignment of sex, the means and standard deviation of the measurements and indices of each sex will be approximately correct. Therefore, a calculation of the chances of error in the determination of the sex of an individual specimen can be made. The correlations between the characters used in sorting are low (Table 2), and, therefore, probability of error will be the product of the chances of each sorting criterion taken separately. The chances of successful assignment of sex are better than 10-1 for the ischium pubis-index, 5-1 for the angle of the sciatic notch, and 2-1 for the interiliac index. Theoretically the number of uncertain cases should be 1%, and there are two possibly intermediate cases in the series of 224 Eskimo pelves.

An independent check on the reliability of this method is possible because Hrdlička had marked his opinion of the sex on 173 skulls of these same skeletons. Our determinations agree with his in all but 8 cases. In 7 of the cases, in which we disagree the pelvis is clearly male or female, and we see no reason to change our opinion. In one of the 2 cases which are doubtful according to our criteria we disagree with Hrdlička, but here he disagrees with himself for he had marked the femur of this individual male and the skull female. Considering all the evidence, we feel that this is the only individual in the series whose sex is in reasonable doubt.

The method of determining the sex of innominate bones described here differs fundamentally from that now used by most anthropologists. According to this method the assignment of sex is the *result* of the measurements, rather than being made prior to the measurements. The difference can be made clear if one considers what would be done if another specimen were added to the series. Traditionally, the sex of the bone would be guessed and then the measurements taken. By the method described in this paper, the measurements are taken first, the position of the specimen in the series is determined, and finally an estimate of the sex is given. The importance of the difference in procedure arises from two sets of factors. If sex is assigned first, then the measurements can do no more than quantify the opinion of the person who guessed the sex. The investigator may be right most of the time, but this can not be proved because all the observer's biases are incorporated into the original sorting. Second, if sex is assigned, it is not known why any particular individual was put into one category rather than the other. Any one of the many criteria may have been used, and, although a good morphologist is probably nearly always correct in his designation, he can neither teach others nor improve his methods, except in the sense that an art can be taught and improved. The present method can be easily taught, and can be improved by devising measurements which separate the sexes more effectively or by adding additional, uncorrelated measurements. In short, the method recommended here is more useful than the traditional anthropological one of depending on personal judgment because: the basis for the assignment of sex is explicit and can be improved, a beginner can do as well as an expert, and it automatically adjusts to the variations in new series.

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THIGH GIRTH AS A MEANS FOR EVALUATION OF NUTRITIONAL STATUS

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DIFFERENT methods have been employed to evaluate the nutritional status of a person, including classical anthropometry, specific gravity determinations, and X-ray pictures. The caloric aspect of nutritional status may be evaluated best by considering the fatness of the body estimated from specific gravity. But such a determination is a long and complex procedure. X-rays may show the thickness of skin and subcutaneous fat very well; but, again, the procedure is very expensive and the delineation between skin and fat is not possible. Thus the use of an adequate, simple anthropometric method still has a rational basis.

In addition to determining body weight (gross and related to age and stature) two techniques seem to be useful: (1) measuring skinfolds by a special caliper; (2) measuring circumferences. Unfortunately, there still is no standardized caliper available and a standard method of measuring skinfolds is lacking. The technique of measuring circumferences, however, is fairly standardized and simple and may yield fair results when measurements are considered in relation to some other measurement such as height or weight.

The data discussed in the present paper were obtained on 311 men 18-23 years old and 435 women 17-23 years old in the central medical clinic of the schools of Ljubljana (Škerlj, '50). The measurements were taken during the academic year 1939-40, the last normal year in Yugoslavia prior to the Italian and German occupation. In the program of systematic measurements of the secondary school and college youths of Ljubljana, chest, waist and thigh girth were measured with a tape. The chest girth was measured high on the thorax, just below the axillae and always somewhat above the nipples, so that it was possible to measure it in both sexes in the same way. Maximum (after inhaling) and minimum (after exhaling) values were determined and averaged. The waist girth was measured above the navel to get the minimum circumference of the trunk. Neither of these measurements can be taken with high certainty and therefore were recorded to the nearest 0.5 cm only. The thigh girth was measured (in mm) around the thickest part of the thigh in the middle of the upper third. The subjects stood with the weight on the measured limb, normally the right one.

In order to ascertain the usefulness of the measurements, the "constitutional" type was determined in both sexes; in females the "plastic" type and the size of the breasts also was considered. "Constitutional" types were labelled "leptosomatic," "mixed," and "eurysomatic"; the "plastic" types, referring to the body mass evaluated by inspection, were labelled "hypo-," "normo-," and "hyper-plastic." The size of the breasts was rated on a 5-point scale.

To find out which of the three circumferences may be the best for evaluating the nutritional status, various correlations were calculated. The results are given in Table 1.

RESULTS

1. In males, chest girth has the highest correlation with stature, and thigh girth the lowest; in females, waist girth has the lowest correlation. All coefficients are rather low.
2. In both sexes, chest girth has the lowest correlation with weight, thigh girth the highest. The coefficients in females are somewhat higher than in males.
3. In both sexes, the correlation between thigh girth and chest girth is lower than between thigh and waist or between chest and waist.
4. Chest girth has the highest correlation with "constitutional" types in both sexes.
5. Of all the measurements, thigh girth shows the highest correlation with "plastic" type.
6. The correlation of the size of the breasts with thigh girth is somewhat greater than with chest and waist girth.

In anthropometric studies chest and waist girth are usually given. But we know that both not only measure bones and soft tissues (muscles and fat), but also the variable volume of some of the viscera; the abdomen may be distended, or the lungs may contain more or less air. Even on *a priori* grounds, the thigh girth therefore seems to be a better indication of the nutritional status of the subject measured. Very probably the same is true of the upper arm girth (Brožek and Keys, '51 and Lasker, '52).

TABLE 1

Correlations of the girths with other characteristics

CORRELATIONS	311 18–23 year old males	435 17–23 year old females
Stature width		
chest girth	.311 ± .034	.299 ± .029
waist girth	.256 ± .036	.168 ± .031
thigh girth	.246 ± .036	.215 ± .031
Weight width		
chest girth	.756 ± .016	.809 ± .011
waist girth	.795 ± .014	.824 ± .014
thigh girth	.854 ± .010	.864 ± .008
Chest with waist girth	.669 ± .021	.789 ± .012
Chest with thigh girth	.620 ± .023	.672 ± .018
Waist with thigh girth	.670 ± .021	.726 ± .015
"Constitution" with		
chest girth	.537 ± .027	.430 ± .026
waist girth	.412 ± .032	.376 ± .028
thigh girth	.381 ± .033	.402 ± .027
"Plastic" type with		
chest girth		.473 ± .025
waist girth		.488 ± .025
thigh girth		.630 ± .019
Size of breasts with		
chest girth		.387 ± .028
waist girth		.406 ± .027
thigh girth		.422 ± .027

The advantages of measuring the thigh girth are clear: it is a rapid, simple, and inexpensive anthropometric method; when measured, the subject can be dressed in underwear or a bathing suit; the correlation with weight is high; even the correlation with the "plastic" types and with the size of the breasts (in females) is quite high. This latter statement is important insofar as the "hyper-plastic" type and the size of the mammae are highly conditioned by fat tissue—as is the circumference of the thigh. As Brožek and Keys ('50) stated, in evaluating "normal" weight, we have to know what we are weighing; one may say the same about measuring circumferences for the purpose of evaluating leanness-fatness. From this point of view it seems that the upper arm and the thigh girth are the best simple anthropometric measures to appraise individual nutritional status. For the present reference sample one would say that (using plus and minus two standard deviations from the mean as limits) men having a thigh girth relative to stature lower than 27 could be considered as lean, those having more than 36 as fat. In women, the mean thigh girth relative to stature is about 35; if it is lower than 29 the subject may be regarded as lean, if more than 41 as fat.

There are two minor disadvantages inherent in this method. The measurement is made near the sexual organs and it is therefore necessary to exercise great tact. Pressure of the tape can be highly arbitrary and it seems best to measure without pressure on the tape. From measuring thigh girth, one can say nothing about the relation of muscle tissue to fat. Better than any other simple measure, however, thigh girth enables one to consider the nutritional status according to the development of the subject's soft tissues as a whole.

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THE DEVELOPMENT OF SEX DIFFERENCES IN BODY DIMENSIONS, EVALUATED IN TERMS OF THE CRITICAL RATIO

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ON the average, the adult man is bigger than the adult woman—his shoulders are broader, the thorax more voluminous, etc. How and when do these differences develop? Even though longitudinal studies have unquestionable advantages, some of these questions can be answered by the use of critical ratios which serve to test the significance of differences between measurements in cross-sectional studies.

TABLE 1

Size of the age groups

	AGE IN YEARS										
	11	12	13	14	15	16	17	18	19	20-23	Total
Boys	75	95	130	147	116	100	104	116	100	114	1097
Girls	94	171	247	260	253	133	137	157	107	54	1613

The present study refers to children of secondary schools and colleges of Ljubljana who were investigated during the academic year 1939-40 (Škerlj, '50). The ages were 11 to 23 years (see Table I). Measurements were taken by standard technique (Martin, '28), except the chest girth which was measured, in both sexes, high in the axillae and above the nipples. The measurements include the following: stature, weight, head length and breadth, bi-acromial, bi-cristal, and bi-trochanteric widths, chest, waist, and thigh girths, and vital capacity (by Hutchinson's spirometer). From these measurements some indices and relative measurements were derived. The children were a random sample of healthy school youth of Ljubljana.

The data were evaluated by calculating the means, the differences between means (D), and their probable errors (PE). The critical ratios (D/PE) were considered significant when the ratio was between 3 and 4.5, and highly significant when it exceeded 4.5. The direction of the differences is indicated by the use of small (b, g) and capital letters (B, G), respectively. The letter indicates the sex in which the means are larger (B for boy, G for Girl). Small o indicates the absence of a significant difference. The results are presented in Table 2.

TABLE 2

Development of sex differences

	AGE IN YEARS									
Characters	11	12	13	14	15	16	17	18	19	20-23
Head length	B	B	B	B	B	B	B	B	B	B
Head breadth	B	b	B	B	B	B	B	B	B	B
Cephalic index	o	o	o	o	o	o	o	g	o	o
Weight	g	o	G	G	o	b	B	B	B	B
Stature	o	o	g	o	B	B	B	B	B	B
Rohrer's index	o	o	o	G	G	G	G	G	G	G
Bi-acromial width	o	o	o	o	B	B	B	B	B	B
Rel. bi-acromial width	B	o	B	b	o	b	b	B	b	B
Bi-cristal width	o	G	G	G	G	g	g	o	o	o
Rel. bi-cristal width	o	G	G	G	G	G	G	G	G	G
Bi-trochanteric width	G	G	G	G	G	G	G	o	o	o
Rel. bi-trochanteric width	G	G	G	G	G	G	G	G	G	G
Chest girth	b	o	o	o	b	B	B	B	B	B
Rel. chest girth	B	b	B	o	o	o	o	o	o	b
Waist girth	o	o	o	b	o	B	B	B	B	B
Rel. waist girth	o	o	o	o	g	o	o	o	G	o
Thigh girth	g	G	G	G	G	G	G	G	G	G
Rel. thigh girth	o	g	g	G	G	G	G	G	G	G
Lorentz' spiroindex	B	B	B	B	B	B	B	B	B	B

Rohrer's index gives the relation between stature and weight by the formula $\frac{\text{weight, in gm}}{\text{stature}^3\text{, in cm}} \times 100$. "Rel." means the respective measurement relative to stature. Lorentz' spiroindex gives the relation of the exhaled air in cm^3 per cm of stature.

The absolute length and breadth of the head is significantly higher in boys during the whole period of observation. Except at 11, 13, 14, and 15 years of age, the girls' cephalic indices are slightly higher.

Weight is significantly greater in girls in the 13th and the 14th year, in boys, from the 16th year on. Stature is slightly greater in girls in the 13th year, but from the 15th year on, boys are significantly taller. Rohrer's index is significantly higher in girls from the 14th year on.

In widths the sexual differences are very interesting. As could be expected, the absolute measurements do not show the same trends as the relative values. The absolute bi-acromial width is significantly higher in boys from 15 years on, the absolute bi-cristal width in girls from the 12th to 15th year of age. The latter is slightly higher in girls till the 17th year when the sex difference disappears. This is in agreement with the faster growth of girls in the first half of the period under consideration. Similarly, the absolute bi-trochanteric width is higher in girls from 11 to 17 years; *later there is no sex difference.*

In girls the relative bi-acromial width tends to be lower than in boys. The relative bi-cristal width is significantly higher in girls from the 12th year on, whereas the relative bi-trochanteric width is higher in girls throughout the whole period.

In boys, the absolute chest and waist girths are definitely higher from the 16th year on. The absolute thigh girth is higher in girls throughout. In the circumferences relative to stature, boys tend to have a larger chest, girls a larger waist circumference but the sex differences are not very marked. The relative thigh girth is insignificantly higher in girls in the 11th year; the difference is slightly significant in the 12th and 13th years, and highly significant from the 14th year on. Finally, Lorentz' spiroindex indicates a significant sex difference throughout the whole period, with the boys having higher values even during the period when girls develop faster (11th to 15th year).

Some anthropometric sex differences are present even before the pubertal age, some only thereafter. Absolute head length and breadth as well as Lorentz' spiroindex, in boys, relative circumferences of hips and thighs, in girls, are significantly larger from 11 years to maturity. The cephalic index and the relative waist girth are, broadly speaking, *sexually indifferent characters.* Stature, Rohrer's index, bi-acromial width, relative bi-cristal width, absolute chest and waist girth *become significantly different during puberty.* Absolute bi-cristal and bi-trochantric widths as well as relative chest girth *become sexually indifferent characters after 18 years of age.* The sex differences in weight reverse themselves around the age of 15 years.

Of the 19 characters investigated, seven are significantly different in the 11th year, six in the 12th, eleven in the 13th and 14th years, twelve in the 15th year, thirteen in the 16th year, and fourteen from the 17th year on.

The results obtained in this investigation contribute to our knowledge of the development of secondary sex differences during the prepubertal, pubertal and early adult ages. Similar studies of other characters in subjects of this age range as well as the investigation of children during the first decade of life would throw additional light on the development of sex differences.

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PREVALENCE OF LEFT-HANDEDNESS AMONG SELECTIVE SERVICE REGISTRANTS

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INTRODUCTION

THE findings presented here on the prevalence of left-handedness among Selective Service registrants examined for military service are based on information obtained from the "Report of Medical History" (Standard Form 89). These individual reports are accomplished at the examining induction stations at the time the registrants are given a medical examination to determine their fitness for military service. The established procedures for the medical processing of registrants require that a medical history be taken on each examinee (Special Regulations, '51).

This report form is designed primarily to provide data on the examinee's health status (past and present) and also some similar data regarding his blood relations and other relatives. The questions on the form are therefore predominantly medical. The medical information reported on the form is used by the examining physician as a reference when conducting the medical examination. Specifically, it serves to alert the physician to conditions or ailments which ordinarily are not readily discernible.

In addition to the questions about health, the form contains questions regarding the examinee's occupation, employment, and some personal characteristics. Among the last group of questions, is the following question:

"Are you (check one) ☐ Right handed ☐ Left handed."

GENERAL CONSIDERATIONS

The "Report of Medical History" is a self-administered paper-and-pencil form. It is filled out by the examinee in his own handwriting. Neither oral nor written instructions are given for completing the form. Assistance is provided only whenever the registrant has difficulty in understanding the questions; such difficulty arises chiefly with respect to unfamiliar medical terms used on the form.

The reliability of information obtained from this type of form depends, of course, on whether the respondent is able and willing to supply the correct answers to the questions. The respondent may not know the right answer. In the case of the Report of Medical History, it may be especially true with respect to certain medical questions. On the other hand, the respondent may know, but for some reason(s) be unwilling to supply the right answer. This may be true of questions on the form dealing, for instance, with undesirable habits or traits of character (e. g homosexuality, chronic drunkenness, etc.). In these cases, the type of answer may be adversely motivated either by certain social factors (stigma attached to such traits, etc.), or by the individual's desire or lack of desire to be accepted for military service. However in regard to the particular question on handedness, there seems to be no basis to doubt the individual's ability or willingness to give the correct answer.

The answer to this question is what the individual registrant considers himself to be: either right-handed or left-handed. In view of the fact that we are dealing here with an adult group, this particular self-appraisal formed by the individual on the basis of his own experience may be assumed to be generally accurate. It may be also assumed that the information is generally free of bias, in the sense that the answer to the question may be taken as being genuine, since handedness *per se* is not a factor in determining the individual's acceptablity for military service—a fact presumably well-known to the examinee.

This investigation evolved from an inquiry made to the Office of The Surgeon General, Army, as to the proportion of left-handed individuals among personnel of the Armed Forces. It appeared from this inquiry that the information might possibly be used as an index of the prevalence of left-handedness in the total population. Though left-handedness as such is not disqualifying for military service, as previously noted, past studies on left-handedness seemed to suggest that it might be associated to a certain extent with some physical or mental conditions

(Wile, '34) which might be of disqualifying nature. To preclude therefore possible bias that could result from limiting the investigation to Army (qualified) personnel, the study was broadened to include both registrants who were qualified and those who were disqualified for military service. The information was abstracted by means of a hand tabulation from the Standard Forms 89 ("Report of Medical History") that were received by the Department of the Army during the following dates: 19 June, 28 June, and 30 June, 1952.

TABLE 1

Prevalence of left-handedness among qualified and disqualified registrants examined at armed forces examining stations, Continental United States, by army area, 1952[1]

ARMY AREA[2]	QUALIFIED (INDUCED)		DISQUALIFIED	
	Total Number (1)	Number Left-Handed (2)	Total Number (3)	Number Left-Handed (4)
I	1,187	91	610	70
II	1,180	93	1,238	130
III	836	60	1,487	133
IV	530	36	1,233	101
V	1,788	148	759	82
VI	519	43	792	77
Total	6,040	471	6,119	593

The obtained data are shown in Table 1.

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[1] Source: Standard Forms 89 ("Report of Medical History"), received by the Department of the Army during the following dates: 19 June, 28 June and 30 June, 1952.

[2] States within each army area are as follows: *First Army Area*—Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont; *Second Army Area*—Delaware, District of Columbia, Kentucky, Maryland, Ohio, Pennsylvania, Virginia, and West Virginia; *Third Army Area*—Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, and Tennessee; *Fourth Army Area*—Arkansas, Louisiana, New Mexico, Oklahoma, and Texas; *Fifth Army Area*—Colorado, Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, Wisconsin, and Wyoming; *Sixth Army Area*—Arizona, California, Idaho, Montana, Nevada, Oregon, Utah, and Washington.

PREVALENCE RATES BY ARMY AREA AND CHI-SQUARE ANALYSIS

Slightly over 12,000 forms from the Continental United States were hand-tabulated. The tabulation was made separately for the qualified group and the disqualified group (sample groups), and each of these groups was stratified by army area (sample components). (The Continental United States are separated into six army areas which roughly correspond to the geographic subdivisions used by the Bureau of the Census. The states included in each army area are specified in the second footnote to Table 1.)

Because of possible differences in the prevalence of left-handedness between these groups, the prevalence rate of each army area within the qualified group and the disqualified group was computed, prior to deriving rates reflecting the prevalence of left-handedness among all registrants (qualified plus disqualified). A chi-square analysis was then undertaken to determine whether any statistically significant differences exist between the rates of the following sample components: *a.* Between army areas within the qualified group; *b.* between army areas within the disqualified group; and *c.* between the qualified and the disqualified components of each army area and all army areas combined.

As seen from Table 2, the prevalence of left-handedness by army area within the qualified group ranged from 6.8 percent in the Fourth Army Area to 8.3 percent in the Fifth and Sixth Army Areas. However, a chi-square analysis of these rates indicate that the probability (P) of obtaining a chi-square value equal to or greater than that obtained for the qualified group by army area was as large as approximately .85 ($.90 > P > .80$; Table 3, A). In other words, the derived chi-square values indicated a very high probability that the variations between these rates by army area could have arisen by chance alone.

For the disqualified group, the prevalence rates of left-handedness ranged from 8.2 percent in the Fourth Army Area, to 11.5 percent in the First Army Area (Table 2, B). In this case, the probability (P) of securing by chance a chi-square value as great or greater than that obtained for the disqualified group was approximately .15 ($.20 > P > .10$; Table 3, B).

Neither of these groups thus indicated statistically significant differences by army area, either at the 1 percent or 5 percent level of significance. It means that no statistically significant geographic differentials, as determined by army area, were found in the prevalence of left-

TABLE 2

Prevalence of left-handedness among registrants in the Continental United States processed for military service: a. qualified; b. disqualified, and c. total examined (qualified and disqualified), by army area, 1952 *

ARMY AREA AND GROUP	PREVALENCE IN PERCENT		
		Confidence Intervals	
	Percent Left-handed (1)	Confidence Coefficient 0.95 (2)	Confidence Coefficient 0.99 (3)
A. Qualified (Inducted)			
I	7.7	6.2– 9.3	5.8– 9.9
II	7.9	6.4– 9.6	6.0–10.1
III	7.2	5.5– 9.1	5.1– 9.8
IV	6.8	4.8– 9.3	4.3–10.1
V	8.3	7.0– 9.7	6.7–10.1
VI	8.3	6.1–11.0	5.5–11.9
Total U. S.	7.9	7.2– 8.5	6.9– 8.8
B. Disqualified			
I	11.5	9.1–14.3	8.4–15.2
II	10.5	8.8–12.3	8.3–13.0
III	8.9	7.5–10.5	7.1–11.0
IV	8.2	6.7– 9.9	6.3–10.4
V	10.8	8.7–13.3	8.1–14.1
VI	9.7	7.8–12.0	7.2–12.7
Total U. S.	10.1	9.3–10.9	9.0–11.2
C. Total Examined (Qualified & Disqualified)			
I	8.7	7.4–10.0	7.0–10.4
II	8.8	7.6– 9.9	7.2–10.3
III	8.1	6.9– 9.2	6.6– 9.6
IV	7.4	6.0– 8.8	5.5– 9.2
V	8.9	7.8–10.0	7.4–10.4
VI	8.8	7.1–10.5	6.6–11.0
Total U. S.	8.6	8.0– 9.1	7.9– 9.3

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* See "Technical Note," at the end of the article.

handedness among analogous (qualified or disqualified) groups of registrants.

Different results however, were obtained when the prevalence rate of each army area in the qualified group was compared with the corresponding rate of the army area in the disqualified group. In analyzing these rates, three army areas (First, Second, and Fifth) showed chi-square values that were statistically significant at least at the 5 percent level of significance. In the other three army areas (Third, Fourth, and Sixth), none of the chi-square values reached the value corresponding

TABLE 3

Chi-square values *

GROUP TESTED	χ^2	DEGREES OF FREEDOM	PROBABILITY (P)	LEVEL OF STATISTICAL SIGNIFICANCE 0.05	0.01
A. Qualified (by Army Area)	1.977	5	.90 >P>.80	—	—
B. Disqualified (by Army Area)	8.337	5	.20 >P>.10	—	—
C. Qualified vs. Disqualified:					
a. Individual Samples:					
First Army Area	7.167	1	.0077>P>.0073	+	+
Second Army Area	4.952	1	.0269>P>.0254	+	+
Third Army Area	2.194	1	.1473>P>.1380	—	—
Fourth Army Area	1.012	1	.3173>P>.2943	—	—
Fifth Army Area	4.140	1	.0429>P>.0404	+	—
Sixth Army Area	.779	1	.3802>P>.3771	—	—
b. Total (Pooled samples)	13.643	1	.001 >P> 0	+	+
c. Total (Sum of χ^2 of the individual components)	20.244	6	.01 >P>.001	+	+
d. Interaction χ^2 value	6.601	5	.30 >P>.20	—	—

* Relate to the data of Table 1. The chi-square values for "Qualified (by Army Area)" and "Disqualified (by Army Area)" were calculated by the Brandt and Snedecor Method. (See: Snedecor, '50: "A special method of computing chi-square in R × 2 table," pp. 205-206.) For the method used in computing the chi-square values of Qualified vs. Disqualified and a general discussion of chi-square values derived from a pooled sample versus chi-square values obtained by summing the chi-square values of the individual samples, see Snedecor, ('50), pp. 188-193, or Ferber, ('49): pp. 266, 270-275. The "P" values for 1 degree of freedom were taken from Yule and Kendall, ('48): pp. 534-535. Plus sign (+) means "significant" and minus sign (—) means "nonsignificant," at the particular level of significance.

to 1 percent or 5 percent level of significance (Table 3, Ca). However, all differences were in the same direction; that is, each army area in the disqualified group showed a higher prevalence of left-handedness than that shown by the same area in the qualified group (Table 2).

The chi-square value obtained in comparing the over-all (all area combined) prevalence rate of the disqualified group with the over-all rate of the qualified group was larger than the chi-square value for 1 percent level of significance. This held true when the chi-square value was computed by pooling the samples (Table 3, Cb), or by summing the individual chi-square values (Table 3, Cc). The obtained chi-square values of the over-all rates thus indicated that the prevalence of left-handedness among disqualified registrants was significantly higher than among the qualified registrants. The validity of this statement was further corroborated by the fact that the interaction chi-square value was much below that of the 5 percent level of significance ($.30 > P > .20$; Table 3, Cd); this fact suggests that we are dealing with homogeneous populations. (See Snedecor, '50, pp. 188-193.) Restating, the obtained chi-square values strongly suggest that there exist real differences between the prevalence of left-handedness in the disqualified group and that in the qualified group.

ADJUSTMENT FOR DISPROPORTIONALITY

The significantly higher prevalence of left-handedness found among disqualified registrants, when compared with the prevalence rate among qualified registrants, seemingly confirms former findings which have suggested certain association between left-handedness and some physical or mental abnormalities. But apart from this fact by itself, these differences are of importance in the computational sense; namely, in deriving the prevalence rate for the combined (qualified plus disqualified) sample components.

For sample control purposes, distributions of qualified and disqualified registrants, by army area, were obtained from the results of the preinduction examinations of registrants processed during the six-month period from January 1952 through June 1952. These relative distributions are presented in Table 4, under the heading "population," as follows: *a*. Qualified group, by army area; *b*. disqualified group, by army area; *c*. qualified versus disqualified in each army area and all army areas combined. The corresponding distributions obtained from the sample are shown in Table 4, under the heading "sample." In comparing these relative distributions, it readily became evident that the forms in the sample were disproportionately distributed, especially in the relative ratios of qualified to disqualified. For instance, the ratio of "Total U. S.: Qualified" to "Total U. S.: Disqualified" registrants obtained from the sample groups was about 1:1, while the corresponding ratio in the population was about 7:3 (Table 4, Column 3). Analogous differences were noted in the ratios of qualified to disqualified of the individual army areas. Variation in these ratios was expected because of the following fact: Standard Forms 89 of disqualified registrants are received immediately after the preinduction examinations, while those of qualified registrants are received after induction, which takes place at some time after the preinduction examinations. Evidently, this difference in procedure of forwarding the forms may bring about, at any particular point in time, ratios of "qualified" (inducted) to "disqualified" that are different from their original ("population") ratios at the time of preinduction examinations.

Because of these disproportionalities and due to the fact that there were found significant differences between the prevalence of left-handedness in the two groups, the prevalence rates of the combined (qualified plus disqualified) components, whether for each individual army area or all areas, could not be computed by directly combining the corresponding data, as obtained from the sample, without adjusting for disproportionality. Certain disproportionalities were also found in the relative distribution by army area of the qualified group and likewise of the disqualified group. For instance, in the qualified group the First Army Area constituted about 20 percent of the sample-group, while in the "population" this area made up about 23 percent of the total qualified group; in the disqualified group, the First Army Area constituted about 10 percent of this group in the sample, as against 17 percent in the population. (Table 4, Columns 1 and 2). Since no statistically significant differences were found between the rates of the army areas within each of these groups, as stated above, the disproportionalities by army area are naturally of less importance in computing over-all rates for the groups.

The following rates were adjusted for disproportionality: *a.* Over-all rate of the qualified group; *b.* over-all rate of the disqualified group; and *c.* combined rates (qualified plus disqualified) of each army area and all army areas. (These rates may be referred to as "weighted" rates, and all other rates as "unweighted." The procedures applied in adjusting for disproportionality are explained in the "Technical Note," at the end of the article.)

TABLE 4

Relative distributions of qualified and disqualified registrants by army area, and ratios of qualified to disqualified registrants within each army area and for total United States

ARMY AREA	RELATIVE DISTRIBUTION BY ARMY AREA (PERCENT) Qualified (1)	RELATIVE DISTRIBUTION BY ARMY AREA (PERCENT) Disqualified (2)	RATIOS FOR 1,000 EXAMINED, WITHIN EACH ARMY AREA AND FOR TOTAL U. S. Qualified vs. Disqualified (3)
Population [1]			
I	22.68	17.24	730: 270
II	18.18	18.71	667 : 333
III	10.00	21.43	490: 510
IV	6.88	10.23	580: 420
V	34.79	23.45	753: 247
VI	7.47	8.94	632: 368
Total U. S.	100.00	100.00	673: 327
Sample [2]			
I	19.65	9.97	661: 339
II	19.54	20.23	488: 512
III	13.84	24.31	360: 640
IV	8.77	20.15	301: 699
V	29.61	12.40	702: 298
VI	8.59	12.94	396: 604
Total U. S.	100.00	100.00	497 : 503

[1] Based on preinduction examinations of registrants processed during the six-month period from January 1952 through June 1952.

[2] Derived from Table 1.

All (weighted and unweighted) rates are given in Table 2 together with their confidence intervals based on the 0.95 and 0.99 confidence coefficients. (See Mainland '52, pp. 53-56, or any standard book on statistics, for interpretation of confidence intervals, and the "Technical Note," at the end of the article, for the computation of the confidence intervals.)

OVER-ALL RATES

The over-all prevalence rates and their confidence intervals were found to be as follows (Table 2):

a. Qualified—Total U. S.: 7.9 percent of this group of registrants reported as being left-handed. The confidence intervals are 7.2 percent-8.5 percent for 0.95 confidence coefficient, and 6.9 percent-8.8 percent for 0.99 confidence coefficient.

b. Disqualified—Total U. S.: 10.1 percent of this group of registrants reported as being left-handed. The corresponding confidence intervals are 9.3 percent-10.9 percent, and 9.0 percent-11.2 percent, for 0.95 and 0.99 confidence coefficients, respectively.

c. Qualified and Disqualified—Total U. S.: 8.6 percent of all registrants examined were found to be left-handed. The corresponding confidence intervals are 8.0 percent-9.1 percent, and 7.9 percent-9.3 percent for 0.95 and 0.99 confidence coefficients, respectively.

It should be noted that these rates relate to examined registrants within the 19 through 25 age-group. As known, certain groups of registrants are in the deferred classes because of marital status, dependency, occupational specialties, etc., and are not sent for examination. However, judging from the above-stated bases for deferment, there is no reason to believe that there is selection with respect to the prevalence of left-handedness among the registrants forwarded for examination. Consequently, the derived prevalence rates of 8.6 percent may presumably be taken as reflecting the prevalence of left-handedness among all registrants. Moreover, this rate may seemingly be taken as representing the prevalence of left-handedness among the total male population in the Continental United States, beginning with the age when handedness may generally be considered fixed. (Past studies on left-handedness report prevalence rates ranging from 1 to 30 percent of the population; See Wile '34, p. 68; also Hildreth '49.)

SUMMARY

1. Information on the prevalence of left-handedness among Selective Service registrants was obtained from the "Report of Medical History," a form filled out by each registrant at the time he is examined for determining his fitness for military service. It is a self-administered

paper-and-pencil form designed primarily to secure information on the examinee's past and present health status. One of the questions on the form is: "Are you (check one) ☐ Right handed ☐ Left handed."

2. About 12,000 forms were hand-tabulated in this investigation; the forms were about equally divided between the group of registrants found fit for military service (inductees) and the group of registrants found unfit for such service. The forms were tabulated by army area within each of these groups.

3. The following over-all prevalence of left-handedness was found:

a. Qualified—7.9 percent left-handed;
b. Disqualified—10.1 percent left-handed;
c. Total (qualified plus disqualified)—8.6 percent left-handed.

4. A chi-square analysis of these rates revealed that the difference between the higher prevalence rate of left-handedness among the disqualified registrants and that among the qualified registrants is statistically significant. (The probability of obtaining a chi-square value as large or larger than the value obtained in this case was less than .01.) Since left-handedness *per se* is not disqualifying for military service, this seems to suggest that left-handedness might be associated with certain defects which are of a disqualifying nature.

5. No statistically significant differences were found among the prevalence rates of the individual army areas in either of the groups, qualified or disqualified.

6. The total prevalence rate of left-handedness (8.6 percent) found among examined registrants may be taken as representative of all registrants. This rate relates to an adult male U. S. population.

7. The information obtained on handedness reflects what the registrant considered himself to be: right-handed or left-handed.

8. This investigation was limited in scope. There still remains the wider question: If it is true that the prevalence of left-handedness is significantly higher among the disqualified registrants than among qualified registrants, then what are the particular defects or diagnoses with which left-handedness is associated?

TECHNICAL NOTE

1. *Weighted Rates and Weighted Variances. a. General.* As pointed out in the text, samples of two separate groups were taken in investigating the prevalence of left-handedness among examined registrants: one

relating to the prevalence of left-handedness in the qualified (inducted) group of registrants; the other relating to that in the disqualified group. Each of these sample-groups was stratified by army area (Table 1). In examining the number of forms obtained for each army area within each group, it was found that their relative distribution differed from the corresponding relative distribution by army area in the population. (See Table 4, Columns 1 and 2, for comparative distribution of these groups in the sample and in the population.) Consequently, in deriving the over-all prevalence rate of left-handedness for each group (Qualified —Total U. S.; Disqualified—Total U. S.), the rates of left-handedness of the individual army areas (sample components) within each group were weighted according to their relative distribution in the population, in order to correct for the disproportionality in the relative distributions of the sample. Likewise, the variances of the individual army area rates were adjusted for disproportionality.

The over-all group-rates and their standard errors were derived by means of the following formulas:

(1) $\sum w_i p_i$—used for computing the over-all group-rate, where w_i (population proportion) signifies the relative proportion of the particular component in the population, and p_i represents the proportion of left-handedness in the particular component as found in the sample;

(2) $\sigma_p = \sqrt{\sum \frac{w_i^2 p_i q_i}{n_i}}$—represents the standard error of a proportion of a disproportionate sample, where w_i and p_i have the same meaning as in formula (1) above; $q_i = 1 - p_i$; and n_i is the number in the particular sample-component. (See Ferber '49, pp. 89-90 and 137-142, for a general discussion on disproportionate samples.)

b. Qualified: Total U. S. For this group: w_i represents the population proportion of the qualified group in any particular army area, as given in Table 4, Column 1 (Population); p_i is the proportion of left-handed as given in Table 2, Column 1 (Qualified); n_i is the number obtained for the particular army area as given in Table 1, Column 1. For example, in case of the First Army Area: $w_i = .2268$; $p_i = .0767$; $q_i = .9233$; and $n_i = 1{,}187$. To obtain the over-all group-rate (Qualified: Total U. S.), the $w_i p_i$ (weighted proportions of left-handedness) of each army area were computed, summed up, and expressed in terms of percent.

The standard error (σ_p) of the over-all rate was derived by summing the individual $\frac{w_i^2 p_i q_i}{n_i}$ (weighted variances) of the army areas, and extracting the square root of the obtained sum. The standard error (σ_p), expressed in percent, was then used in calculating the confidence limits for the "Qualified: Total U. S." (See 3, below.)

c. *Disqualified: Total U. S.* The same procedures, as those described in *b* for the "Qualified" group, were followed in computing the necessary statistics for this group. The individual w_i for this group is given in Table 4, Column 2 (Population): p_i in Table 2, Column 1 (Disqualified); and n_i—Table 1, Column 3. The corresponding data for the First Army Area, for example, were: $w_i = .1724$; $p_i = .1148$; $q_i = .8852$; and $n_i = 610$.

d. *Combined: Examined (Qualified plus Disqualified).* Since the ratios of "qualified" to "disqualified" in the samples were also found to be different from their relative distributions in the population, the problem of disproportionality was encountered in computing the combined prevalence rates (qualified plus disqualified) for each army area and for all army areas, as well as in deriving the confidence limits for these rates. (Compare the relative ratios as given in Table 4, Column 3, for the sample and the population.) The above-stated formulas (*a*, above) were, therefore, used in computing total prevalence rates and the standard errors of the combined rates for each individual army area, as well as of all army areas. For these groups, w_i is the respective ratio of the number qualified to the number disqualified as given in Table 4, Column 3 (Population): p_i is the respective proportion of left-handedness (Table 2, Column 1); n_i is the respective number (Table 1, Columns 1 and 3). Using the First Army Area again as an illustration, w_i are: .730 and .270; p_i—.0767 and .1148; q_i—.9233 and .8852; and n_i—1,187 and 610, for qualified and disqualified components, respectively.

2. *Unweighted rates.* The standard errors of the rates of the individual army areas within the qualified group or disqualified group were computed by the standard formula for proportions: $\sigma_p = \sqrt{\frac{p_i q_i}{n_i}}$

3. *Confidence Intervals. a. Unweighted rates.* The confidence intervals for the unweighted rates were computed by the following formula adapted from Mainland ('48) pp. 25-26, for $p \leq 0.1$:

$$(A \pm F\sqrt{Aq} + \text{appropriate correction term})/n,$$

where A is number of A's in the sample (in our case, the number left-handed); F is the number of standard errors required for the particular confidence coefficient, i. e., 1.96 and 2.58 for 0.95 and 0.99 confidence coefficients, respectively; $q = 1 - p$, where p in our case is the proportion of left-handed in the sample; the appropriate correction term is as given in Mainland ('48), Table III, p. 135; and n is the sample size.

Expressed in our terminology, the above-stated formula is:

$$p_i \pm F\sigma_p + \text{correction term}/n.$$

For $p > 0.1$, the confidence intervals were computed by interpolation from Mainland ('48), Table II, p. 131.

b. Weighted Rates. For the weighted rates (total qualified; total disqualified; and the combined rates for qualified plus disqualified for each army area and all army areas), no correction term (*a*, above) was used in computing the confidence limits. (See Snedecor, '50, p. 193.)

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THE AGE FACTOR IN BODILY MEASUREMENTS OF ADULT MALE AND FEMALE MEXICANS[1]

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DURING a study of adult Mexicans it was noted that there are significant decreases with age in such overall dimensions as stature and sitting height, and increases with age in chest dimensions and various measurements of the head and face. Of course it has long been known that growth does not cease at some fixed age. As early as 1899, Pfitzner measured large series of adults and showed changes with age in stature, sitting height, the head dimensions, bizygomatic diameter and face height. Nevertheless, it has been customary in anthropological studies of race to treat data on all individuals over some arbitrary age (usually 18 years) as comparable (Martin '28). It would be desirable to take the age factor into account.

The purpose of the present paper is to indicate to what extent comparisons of measurements on groups of unrelated adults are affected by differences in the ages of the individuals. For this purpose one series has been selected to represent a single small community, Paracho, Michoacán, Mexico. With the hope of limiting the range of environments involved, a random sample of individuals who had never migrated from Mexico is used. For comparison with these 268 sedentes measured by the author in Paracho in 1948, a series of 608 adults measured in various parts of Mexico by Goldstein ('43) is utilized.

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[1] The support of field work in Mexico by the Wenner-Gren Foundation for Anthropological Research and the assistance of Prof. Pablo Velasquez G. and Miss Bernice Kaplan is gratefully acknowledged. Dr. M. S. Goldstein kindly made his original records available and has read the manuscript and offered valuable criticisms.

METHODS

The techniques of measurement are described elsewhere (Lasker '52, and Goldstein '43). In comparing the data of Lasker with those of Goldstein or others, it is well to bear in mind that there are probably personal differences in the definition of landmarks and the techniques of measurement. Absolute measurements, therefore, are not compared directly. The personal equation, however, should not greatly influence the comparison of differences. In the descriptions of the findings which follow, categorical statements of a difference or use of the phrase "significantly different" refer to mean differences of at least twice the standard error; while "tendency" refers to differences not reaching this level of significance. The age curves for various measurements are recorded in Figures 1 to 4. In the graphs, solid lines pertain to Lasker's data; broken lines to Goldstein's; solid circles indicate males; open circles indicate females. In Lasker's material age is recorded to the last birthday; Goldstein ('43, p. 35) recorded age to the nearest birthday. Not all individuals were measured in every dimension: head height, especially, was omitted in many of Goldstein's protocols, and—because of loss of teeth—facial heights were omitted in some individuals in the Paracho series. The range in number of observations for any age group is indicated in tables 1 and 2, but for most dimensions the larger number of individuals were measured. In all series the 21–30 year old group is the most numerous and, unless otherwise specified, age trends refer to the comparison of this group with older groups—especially with the 51–up age group. Because of the small number of individuals over 51 years old in Lasker's male series, any judgment based on failure of a measurement to show significant changes in this age group should be considered tentative.

FINDINGS

General size. The individuals studied in Paracho were not weighed. For Goldstein's series weight continues to increase with age except for the oldest males.

For both Goldstein's series and our own, the older individuals are slightly shorter. This difference is statistically significant except for the Paracho females series. When the 80 and 90 year-old males are excluded, however, the coefficient, of correlation between age and stature is not statistically significant. For Paracho males 18–73 years old, $r = -0.12$.

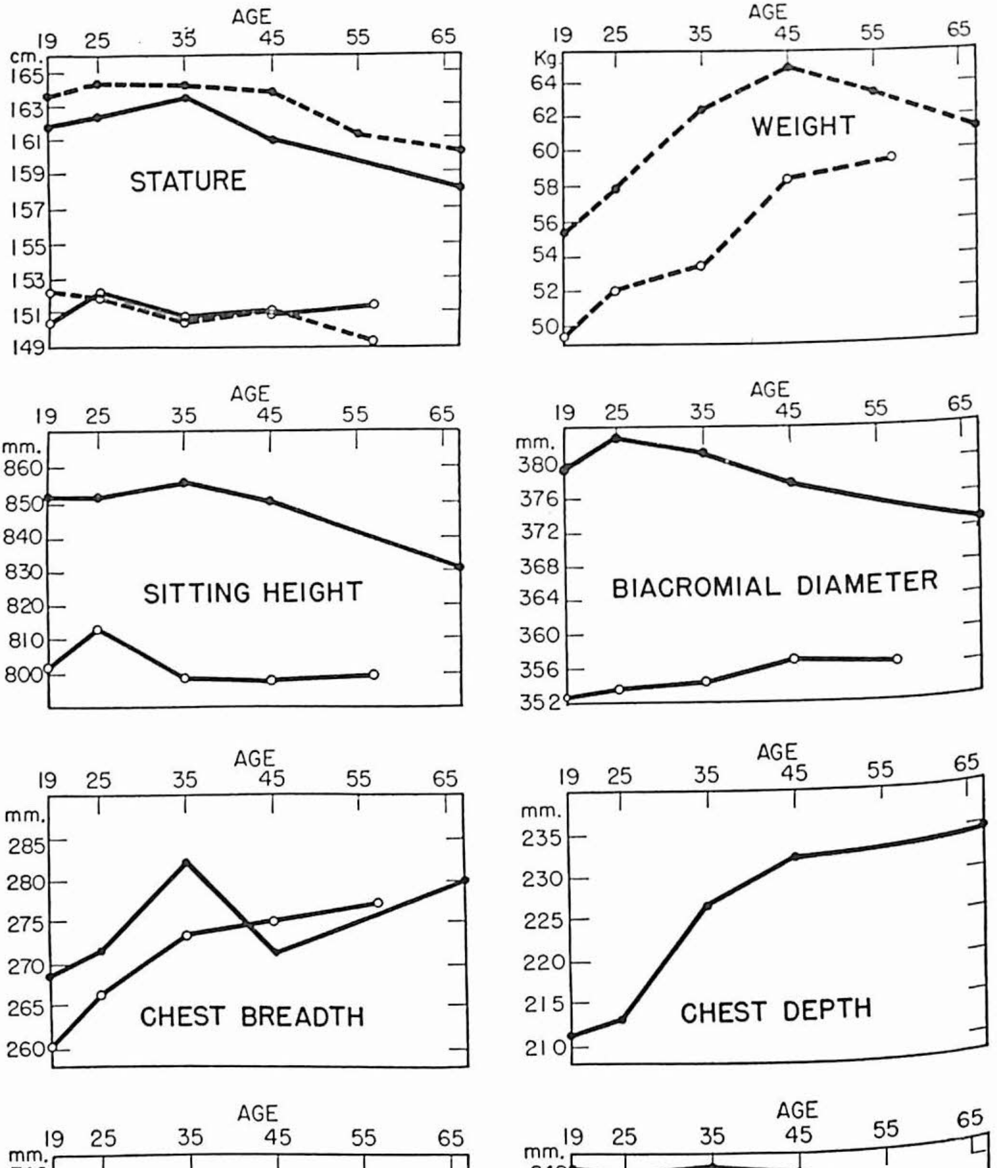

FIG. 1. GRAPHS SHOWING MEAN MEASUREMENTS OF MEXICANS OF DIFFERENT AGE GROUPS.

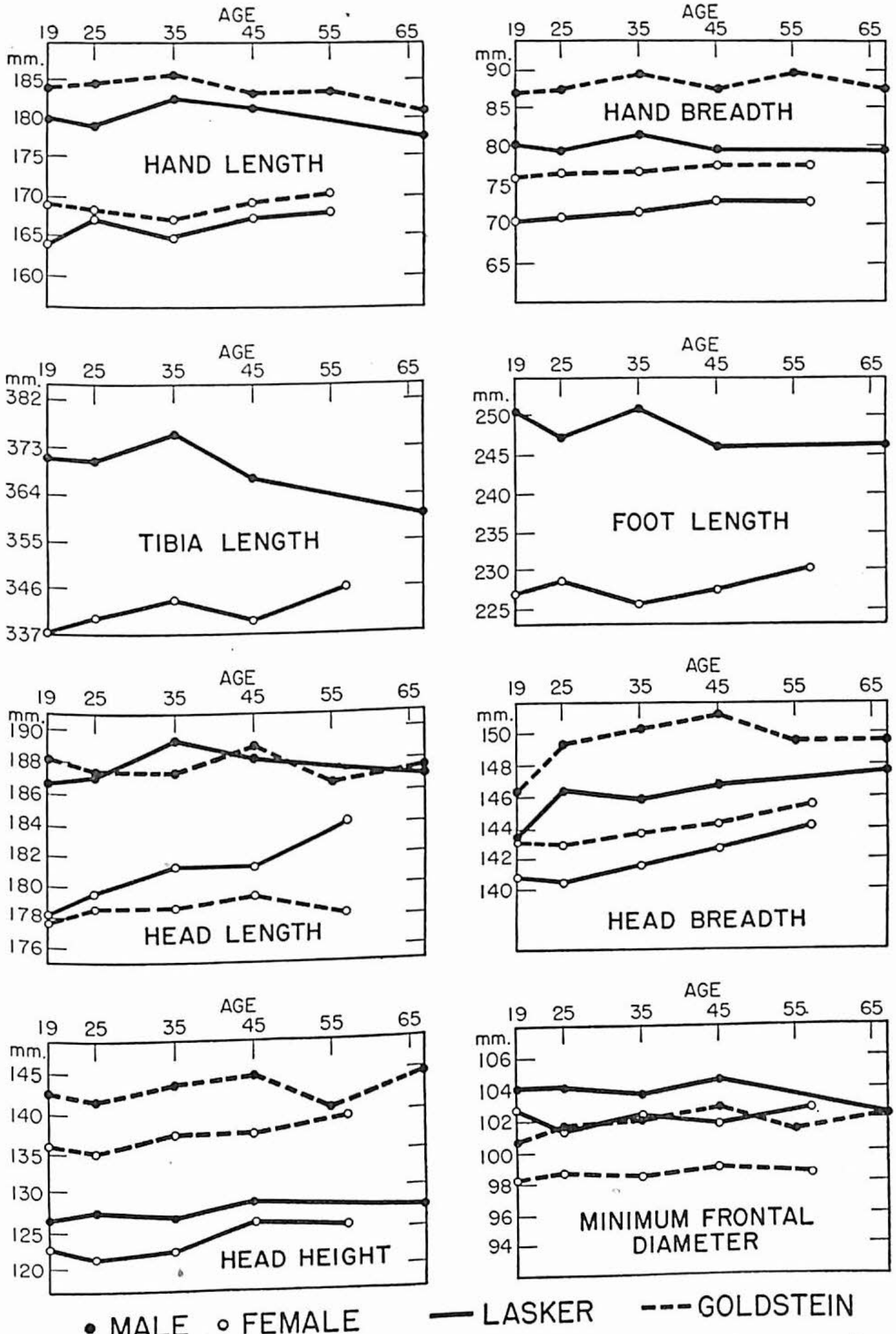

FIG. 2. GRAPHS SHOWING MEAN MEASUREMENTS OF MEXICANS OF DIFFERENT AGE GROUPS.

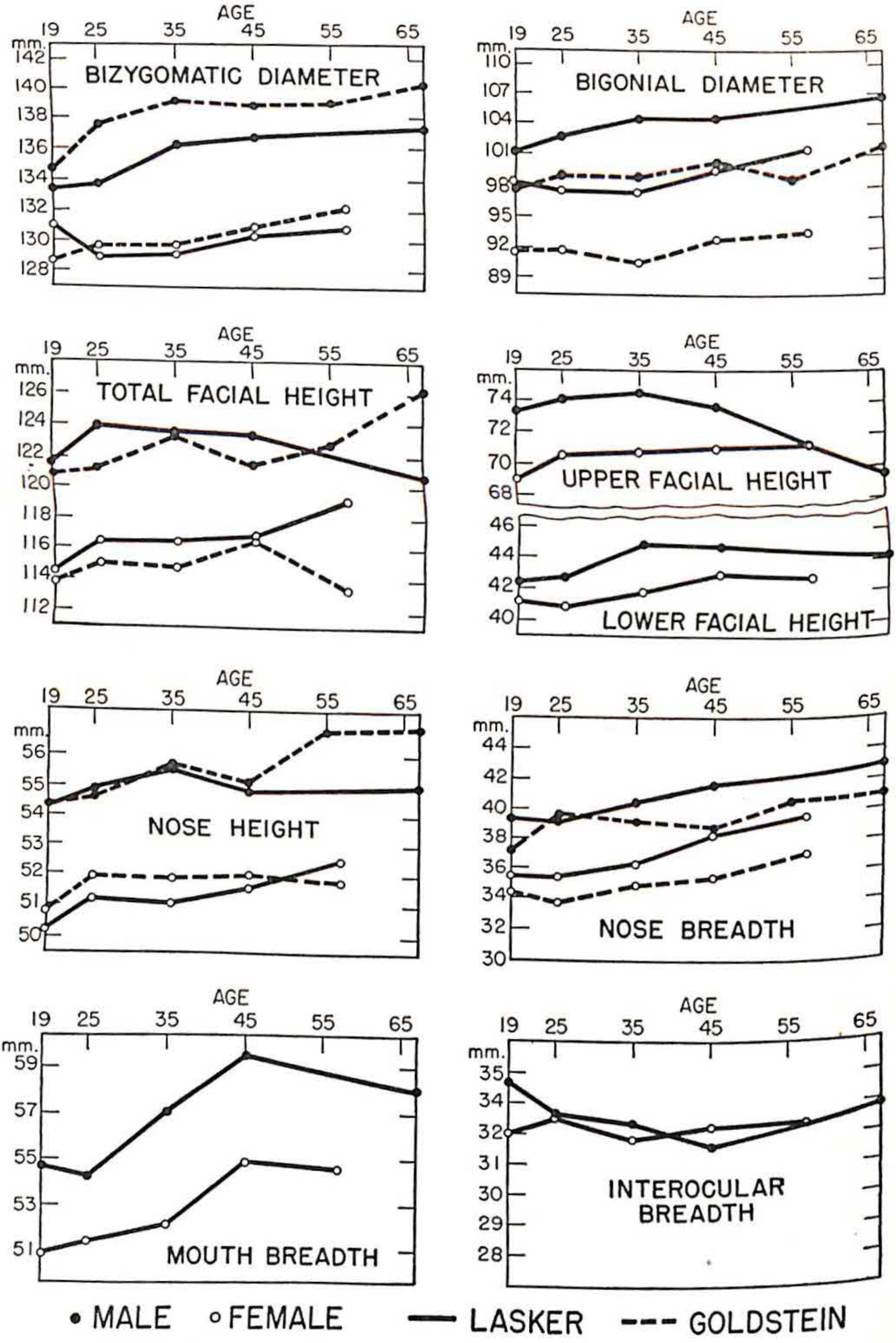

FIG. 3. GRAPHS SHOWING MEAN MEASUREMENTS OF MEXICANS OF DIFFERENT AGE GROUPS.

Trunk dimensions. Data are available only for the Paracho series. Like stature, sitting height shows, and biacromial diameter tends to show, a decrease with age in the males. There is a less marked decrease in sitting height in females than in males. Chest width increases and biacromial diameter tends to increase with age in females. In males, chest depth increases with age and chest breadth tends to do so.

Dimensions of the extremities. On the extremities only the hand dimensions were measured by Goldstein. For these the age curves closely parallel those from Paracho data. For the Paracho series, the lengths of the total arm, radius, tibia, and foot were also measured. All of the measurements of the limbs show a tendency to be smaller in males after the 31–40 year-old period. For the females, however, there is, if anything, a tendency to larger dimensions with increased age, especially after 31–40 years of age.

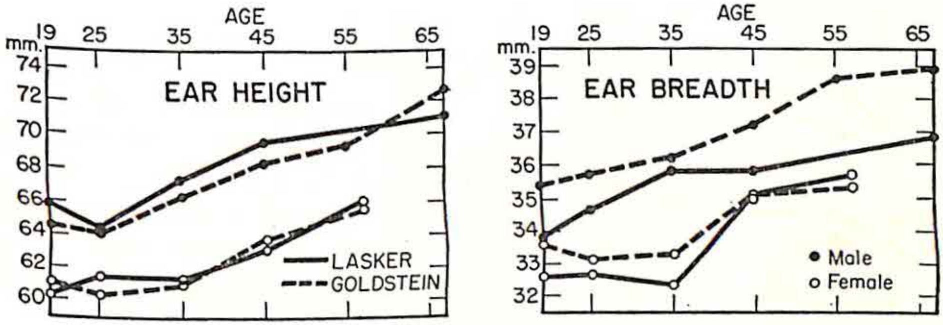

FIG. 4. GRAPHS SHOWING MEAN EAR LENGTH AND BREADTH OF MEXICANS OF DIFFERENT AGE GROUPS.

Head dimensions. In head length there is little tendency to differ with age except for an increase with age in the Paracho females. In head breadth and head height there is a significant increase with age in both female series and a tendency to increase is also seen in the males. Despite the fact that Goldstein's data yield higher values than ours for head breadth and, especially, head height (he uses porion-bregna height, we use tragion-vertex height), his age curves for these dimensions are essentially parallel to those drawn from Paracho data. Minimum frontal diameter and interocular width show no appreciable trends.

Face dimensions. The facial widths (bizygomatic diameter and bi-

TABLE 1

Mean Dimension (in mm.) by Age

PARACHO SEDENTES (LASKER)

	MALES						FEMALES					
	I	II	III	IV	V	Significant differences	I	II	III	IV	V	Significant differences
Age group (in years)	18–20	21–30	31–40	41–50	51–up	V less II	18–20	21–30	31–40	41–50	51–up	V less II
Number	19	32–33	27–28	14–15	7–16		14	38–39	34–37	28–32	26–35	
Mean age (in years)	19.4	25.0	36.9	48.0	68.0		19.4	25.6	36.1	46.4	59.8	
Stature	1618.9	1624.0	1634.6	1609.2	1581.0	–	1504.2	1520.5	1507.3	1509.3	1514.8	o
Sitting height	852.0	852.0	855.7	851.3	831.5	–	802.1	812.8	798.2	797.8	799.6	–
Biacromial diameter	379.3	382.9	381.2	377.9	372.8	o	352.4	353.5	354.3	356.8	356.2	o
Chest breadth	268.9	271.7	282.5	271.1	280.0	o	260.3	266.6	273.5	275.1	277.2	+
Chest depth	211.6	213.3	226.8	232.2	234.6	+						
Arm length	735.4	734.8	736.8	735.1	727.8	o	669.3	680.1	676.8	678.4	685.2	o
Radius length	248.2	247.7	248.3	247.8	245.2	o	226.6	228.8	228.4	230.4	230.2	o
Hand length	180.0	179.1	182.6	181.4	177.9	o	164.3	167.4	164.9	167.4	168.1	o
Hand breadth	80.1	79.6	81.4	79.3	79.1	o	70.6	70.8	71.6	72.9	72.3	o
Tibia length	370.8	370.3	375.5	367.3	360.3	o	337.6	340.3	344.1	339.6	346.2	o
Foot length	250.5	247.1	250.9	245.9	245.9	o	227.0	228.7	225.6	227.1	230.2	o
Head length	186.7	187.1	189.3	188.3	187.1	o	178.2	179.6	181.3	181.2	184.1	+
Head breadth	143.4	146.2	145.9	146.7	147.6	o	140.9	140.4	141.6	142.7	144.1	+
Head height	126.5	127.4	126.5	128.4	127.8	o	122.9	121.1	122.5	126.0	125.4	+
Minimum frontal diameter	104.0	104.1	103.8	104.6	102.2	o	102.9	101.6	102.2	101.8	102.9	o
Interocular width	33.6	32.7	32.4	31.6	32.9	o	32.0	32.5	31.9	32.2	32.3	o
Bizygomatic diameter	133.4	133.8	136.2	136.8	137.2	+	131.0	129.0	129.1	130.6	131.0	o
Bigonial diameter	101.2	102.7	104.2	104.3	107.1	+	98.6	97.7	97.5	99.7	101.7	+
Total facial height	121.6	124.0	123.6	123.5	120.9	o	114.5	116.4	116.5	116.9	119.2	+
Upper facial height	73.3	74.1	74.7	73.6	69.3	o	69.0	70.5	70.7	71.0	71.4	o
Lower facial height	42.3	42.6	45.0	44.7	44.2	o	41.0	40.8	41.6	42.9	42.5	+
Nose height	54.3	54.9	55.5	54.8	55.0	o	50.1	51.2	51.0	51.6	52.5	o
Nose breadth	39.4	39.0	40.3	41.6	42.9	+	35.6	35.5	36.2	38.2	39.6	+
Mouth width	54.7	54.2	57.0	59.2	57.5	+	50.9	51.5	52.2	54.8	54.5	+
Ear breadth	33.8	34.6	35.9	35.8	36.8	+	32.6	32.7	32.4	35.0	35.7	+
Ear height	65.8	64.2	67.4	69.5	71.0	+	60.1	61.4	61.2	63.1	66.0	+

+Oldest group larger by two or more times the standard error of the difference.

–Oldest group smaller by two or more times the standard error of the difference.

o Difference not statistically significant.

TABLE 2

Mean Dimension (in mm.) by Age

MEXICANS (GOLDSTEIN)

	MALES						FEMALES					
	I	II	III	IV	V	Significant differences	I	II	III	IV	V	Significant differences
Age group (in years)	18–20	21–30	31–40	41–50	51–up	V less II	18–20	21–30	31–40	41–50	51–up	V less II
Number	28–37	71–107	21–28	26–40	63–86		37–49	70–92	22–41	58–72	27–46	
Mean age (in years)	19.1	24.9	33.7	45.9	58.3		19.0	24.4	35.1	45.5	57.3	
Weight (in kg.)	55.5	58.0	62.5	65.1	61.2	o	49.4	52.1	53.5	58.6	59.5	+
Stature	1636.7	1644.0	1642.2	1638.5	1603.2	–	1524.3	1519.8	1505.6	1510.9	1492.8	–
Hand length	184.0	184.9	185.9	183.3	181.2	o	169.3	168.2	167.3	169.5	170.5	o
Hand breadth	87.2	87.2	89.5	87.5	87.2	o	76.2	76.6	76.8	78.7	78.6	+
Head length	188.2	187.4	187.4	189.0	187.5	o	177.7	178.6	178.7	179.4	178.1	o
Head breadth	147.2	149.2	150.2	151.0	149.5	o	143.1	143.0	143.8	144.1	145.5	+
Head height	142.4	141.5	143.7	144.7	144.4	+	136.0	135.0	137.4	137.4	139.7	+
Minimum frontal diameter	100.9	101.7	102.1	103.0	102.3	o	98.4	98.8	98.4	99.0	98.5	o
Bizygomatic diameter	134.9	137.6	139.1	139.0	140.3	+	128.9	129.9	129.8	131.0	132.3	+
Bigonial diameter	97.8	99.0	98.7	100.4	102.0	+	91.7	91.9	90.8	93.1	93.6	o
Total facial height	120.9	121.4	123.4	121.6	126.3	+	113.8	115.0	114.9	116.6	113.4	o
Nose height	54.3	54.6	55.6	55.2	56.9	+	50.8	52.0	51.8	52.0	51.8	o
Nose breadth	37.2	39.5	39.0	38.8	40.9	+	34.2	33.9	34.9	35.3	37.0	+
Ear breadth	35.4	35.7	36.2	37.2	38.8	+	33.6	33.1	33.3	35.1	35.4	+
Ear height	64.5	64.1	66.3	68.3	72.7	+	61.0	60.3	61.1	63.8	65.7	+

+ Oldest group larger by two or more times the standard error of the difference.

– Oldest group smaller by two or more times the standard error of the difference.

o Difference not statistically significant.

gonial diameter) manifest an increase with age or a steady tendency in that direction in both sexes and for both sets of observations. Total morphological face height is greater in older females in Paracho and in older males in Goldstein's series. A parallel increase is to be observed for lower facial height in Paracho females, and the same tendency is seen in upper facial height. Paracho males of the oldest groups, however, show a tendency to decrease in all three face height dimensions; a majority of the individuals in the oldest age group had lost teeth with consequent reabsorption of alveolar bone and facial shortening. Nose height shows an increase with age in Goldstein's male series and a similar tendency in Paracho females.

As for those measurements primarily dependent on soft parts, nose breadth increases steadily with age in all series; mouth width also increases with age, although not in the oldest group; ear dimensions, especially height, also manifest steady increases with age. These changes are not only statistically significant but are of considerable magnitude.

Sex differences. In a number of measurements (stature, sitting height, biacromial diameter, chest width, total arm length, radius length, hand length and breadth, tibia length, foot length, total and upper facial height and nose height) the trend is for older females from Paracho to be larger, and older males to be smaller. At least the curves for the two sexes converge at the older ages. In general the dimensions involved are the ones most highly correlated with stature and which therefor best show general size factors (Lasker '46). No ready explanation suggests itself. Goldstein's data contain no trunk measurements; his only extremity measurements, the hand dimensions, do, however, suggest convergence of males and females in the older age groups.

DISCUSSION

Adult males from Paracho, and to a lesser extent the other Mexican series, show a close similarity in age changes in measurements to a series of nearly 10,000 Irish males described by Hooton and Dupertius ('51). In both series stature and sitting height reach a maximum in the thirties and decline thereafter. Arm length in Paracho males and span in the Irish also reach their maximum in this decade. Chest dimensions increase throughout life in men in Ireland as does chest depth in men in Paracho. In the head dimensions the parellelism is not quite so close. Facial breadths, notably the bizygomatic and bigonial diameters, and the nose breadth increase at least into the fifties in both studies, but in facial height and nose height the Irish show continued increases longer than the Paracho males series and resemble Goldstein's Mexican series more closely.

Hooton and Dupertius were apparently surprised at their finding of a continuous increase in facial dimensions during the ages when most other measurements were decreasing, for they say of the upper facial height that, "rather astonishingly, this measurement (nasion-prosthion) continues its increase through the 50–54 year age group," and of bigonial diameter that, "it is very difficult to avoid the conclusion that bigonial increases up to old age . . ." Yet this is not a phenomenon peculiar to the Mexican and Irish studies. Pfitzner (1899) presented evidence that increase in dimensions of the face probably continues at least to the 51–60 year old group in Alsatians. Goldstein ('36) compared Jewish males over 60 years of age with young adults and, in this group also, the facial breadths are larger in the old individuals but facial lengths other than nose height are smaller because of loss of teeth and attendant alveolar absorption. In a survery of 1,067 adult male Albanians, Coon ('50) reported increases in total facial height throughout life, and in bizygomatic diameter until the late forties. Using the same series of American soldiers as Randall, Baer (personal communication), in a study extending only up to age 33, finds significant increases in facial length and breadth throughout the period under consideration.

The curves for age changes reported for Mexico are essentially similar to the findings in other groups. The chief factors responsible for the age changes apparently cut across geographic and racial boundaries.

Any of three types of factors may account for the age differences (Morant '49). 1. There may be an actual change with age. 2. There may be a shift in the population norms so that the later born (and hence younger) individuals differ from those born some years sooner. 3. A selective death rate might eliminate a disproportionate number of individuals of some particular type.

That the first factor is an important one in the present series is suggested by a number of parallels to the results of Büchi ('50). In his analysis the second and third factor were excluded, for he re-examined the same series of 196 Swiss adults after an interval of nine years. Actual changes recorded included a decrease in stature, but in sitting height the decrease was limited to the oldest ages. Length of the inferior extremity and span decreased with age in Büchi's study. However, the former was derived by subtracting sitting height from stature, and span is also a composite measurement into which functional factors enter. Therefore, these decreases are not evidence for a shortening of bones as would be decreases in such measurements as tibia or radius length. It is unfortunate that measurements were not published for at least one of the long bones. In another place, however, Büchi ('49) does give data for hand length and breadth; these continue to increase in size except in the oldest age group.

In Paracho, males in the oldest group have significantly shorter tibiae than those in the 31–40 year old group. In such an absolute diminution with age in length of long bones, it is possible that some selective factor is at work. One such factor might be an overall increase in size of the later-born generation. Bowles ('32), among others, has controlled the age factor and traced a secular trend to increased body size in various parts of the world. Although the same influences might be expected to hold for both sexes in Mexico, it should be noted that the tendency of extremity measurements to decrease in size with age was recorded for males only.

An alternative factor, and one which might affect the male series but not the female series, is the selection of emigrants. Few females have left Paracho, but a majority of the adult males of the community have been in the United States for longer or shorter periods of time. As emigrants are in general somewhat larger than sedentes (who alone are considered in this study) and as some of the younger sedentes are really pre-emigrants, the downward trend in size with age might be the effect of selective migration. This would account also for differences between male and female curves. However, migrants who first left after the age of 27 are not appreciably different from sedentes. In fact, as we have shown in another place (Lasker '52), the more tenable conclusion is that the chief cause of the larger size of those who emigrated when still young is some factor in the environment during this period rather than a difference at the time of migration. There was little to suggest the influence of selective migration.

As for selective death rates, there is no evidence to support the hypothesis. For Büchi's findings, where the changes are shown to occur in individuals, such a factor would be excluded. Morant ('49) also finds the hypothesis unacceptable, although Hooton and Dupertuis ('51) give it some credence.

One way in which measurements may vary with age is through changes in the soft tissues. This is obviously probable for such measurements of cartilagionus parts as the dimensions of the ears and nose (especially breadth). Stature, too, may be influenced through changes in the intervertebral fibrocartilages. Trotter and Gleser ('51) have shown that as between younger and older individuals with identical length of long bones, the older individuals are shorter in stature.

Fat may also influence many measurements. It seems probable that all circumferences, the chest dimensions, and other trunk diameters are influenced by state of fatness. This is indicated in Randall's ('49) study based on a large number of individuals between the ages of 17 and 26, although the measurements published include few of those standard to anthropology. Keys and his associates ('50) have measured the decrease in numerous dimensions during partial starvation. It is possible that changes in the head and face also, to some extent, may be affected by the amount of overlying soft tissues; Ivanovsky ('23) has reported that head and face dimensions decrease during starvation.

Increase in head dimensions has been reported by Büchi for circumference, length, breadth and minimum frontal diameter. His data agree well with our observation that the older individuals have the larger head dimensions, especially breadth and height, except for the very oldest group where the trend is reversed. In bizygomatic diameter, morphologic face height and bigonial diameter also, Büchi demonstrates a continued growth which is reversed only in the oldest age group; and in upper facial height the continued growth is even more striking. In general, Mexicans show this same tendency toward larger faces in the older groups. There is a strong suggestion that increased size of the face may to some extent be caused by appositional growth of bone although there may possibly be some changes in overlying soft tissues also. As Hooton and Dupertuis ('51) say in speaking of bigonial diameter: "We have either to press the selective explanation very far indeed, or admit that growth changes (in the way of increment) continue for a much longer time than most anthropologists have supposed to be the case."

SUMMARY

1. Differences in measurements by age group for 268 adult Mexican sedentes from Paracho, Michoacán, are compared with similar data for 608 adult Mexicans measured by Goldstein.

2. On the average, stature and sitting height are smaller in individuals in the older age groups than in the 21–30 year-old group. Measurements of the limbs show a tendency in the same direction, at least for males.

3. Measurements of the chest and of the head show less consistent tendencies, but some of these dimensions are significantly larger in the older age groups. Facial measurements, especially breadths, are more consistently larger in older groups. The soft parts of the nose, mouth and ears are significantly larger in the older than in the younger adults.

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THE DETERMINATION OF PHYSICAL TYPE IN CHILDREN

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INTRODUCTION

WHEN we wish to characterise individuals physically (as with any other kinds of classification) we seek the fewest differentia covering the widest number of attributes. Therefore, we can first refer to the overall size, next the general shape or proportions, and lastly we can pick out special characteristics or peculiarities. Whilst the classifying principles should cover as wide a sphere of influence as possible, at the same time they should be functional unities rather than mere aggregates of unrelated parts; the concept of type meets these requirements. The first problem is to determine the type basis as given by the grouping of the measurements and the second problem is to determine how the individuals are distributed in respect of this basis. The determination of the basis of physical types can either be made arbitrarily and subjectively or it can be done objectively by partitioning the relations between different physical measurements, using factor analysis of correlations or co-variances. The second stage of allocating individuals to their type and measuring their type strength is necessary if practical use is to be made of the first, and again this can be done objectively. There is no need here to enter into the question of the validity of the methods of factor analysis or to be concerned with its theoretical aspects. We need merely recognise that factor analysis has its uses in classifying anthropometric data and, accepting this standpoint, the purpose of the present paper is to extend its application to measurements of children—where far fewer studies have been made than in the case of adults. This is of two-fold importance, first, because the question of how soon adult types (about which there is a large measure of agreement) can be recognised, is important, and second, because studying physical types in children where growth is still proceeding provides helpful information in interpreting the genesis of adult types. The data presented go rather further than most studies in including measurements of individual type strength and its constancy over a period.

MATERIAL

The present paper sets out the results of factorizing measurements of various groups of children in Britain, together with a comparison of a similar analysis of measurements of American children of the U. S. Bureau of Agriculture Survey made for clothing purposes. (O'Brien et al., '41.) The English children were from three social groups represented by children from the best homes attending fee-paying (private) schools (Group A); from free local authority schools in good neighborhoods (Group B); and from free schools in the poorest neighborhoods of a number of industrial towns (Group C).

Altogether 1,430 private school children and 1,537 free school children were measured and clinically examined.[1] The age range was from 5-18 years. After three years the series of measurements was repeated on the children still attending the schools.

Twenty measurements were correlated in Groups A and C. and the same plus 13 additional measurements in Group B. The correlations were derived from the deviations about the mean measurements for each year.

All the correlations were positive and all but 5% were significantly different from zero. Practically all the low correlations were between subcutaneous tissue and the length measurements. When the correlations were transformed into z coefficients to test how far corresponding coefficients differed from one group to another, it was found that only 2.5% of the coefficients (boys) and 3.1% (girls) differed significantly between social groups of the same age, and 3.5% (boys) and 4.6% (girls) of the coefficients differed significantly from one age group to another (3 s. e. of difference). These results showed that the relations between any one measurement and others were very constant and the z coefficients were, therefore, combined to produce one table of correlations for each sex. The average "within year" correlations for each sex[2] are given in table 1 (figures for boys being above the diagonal and for girls, below).

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[1] For details of description and analysis of the clinical assessment used see Adcock, Hammond and Magee, '47.

DETERMINING THE TYPE BASIS

Analysis of the correlations and comparison of factor results.

Each table of correlations was factorized using Burt's multiple general factor analysis with communalities for the first three factors in the leading diagonal (Burt, '40). The simple summation method was used, except for the combined groups, where the least squares method was used. The saturations for the first general factor and two type factors of each group are set out for comparison in table 2 and table 3 gives the comparison of Group B and the American children's clothing survey results. A more precise indication of the agreement between the factor pattern from one group to another is given by correlating the order of the factor saturations. The rank order correlations average .83 for boys and .87 for girls in the case of the general factors, .94 and .97 for the main type factor, and .74 and .77 for the subsidiary type factor. Even when different batteries of measurements as well as different groups of children are involved, as in table 3, there is considerable agreement, as the measurements which are common to the batteries tend to maintain their relative positions. Thus the 11 measurements common to the two studies correlate to the extent 0.95 in respect of the general factor saturations and 0.90 for the first type factor saturations with an average difference of only .017 in the general factor saturation coefficients. The

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[2] The tables of correlation for different age and social groups are available if required, together with particulars of the measuring procedures.

TABLE I

CORRELATIONS BETWEEN MEASUREMENTS

BOYS

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Weight	1		.7612	.7348	.6221	.6697	.6895	.6447	.6800	.6831	.8094	.7537	.7989	.7888	.7574	.7668	.9177	.5276	.7723	.6190	.3140	1
Height	2	.6802		.8206	.8994	.8148	.7752	.5132	.7312	.6036	.5781	.5020	.5936	.4590	.5161	.5528	.5613	.4763	.6732	.5525	.1184	2
Sitting Height	3	.6722	.8275		.5342	.6396	.6636	.5220	.6557	.5976	.5673	.4695	.5578	.4695	.5449	.5513	.5382	.4682	.6608	.5632	.1122	3
Leg length	4	.4998	.8622	.4823		.7513	.6892	.4076	.6291	.4738	.4552	.4053	.4952	.3474	.3850	.4520	.4628	.4023	.5586	.4277	.0092	4
Arm length	5	.5670	.8044	.5988	.7859		.7243	.4100	.7235	.5105	.5275	.4438	.5184	.3989	.4285	.5065	.4891	.4307	.5974	.4901	.0122	5
Foot length	6	.6048	.7458	.6262	.7306	.6991		.5620	.7540	.5752	.5260	.4833	.5587	.4275	.4626	.5771	.5477	.4553	.6185	.5040	.0099	6
Foot breadth	7	.5922	.4862	.4770	.3713	.4156	.4910		.5623	.6311	.5040	.4534	.4981	.4837	.5615	.6014	.5573	.4019	.5546	.4641	.1293	7
Hand length	8	.5798	.6984	.5997	.5898	.7320	.7500	.5167		.6345	.5257	.4628	.5363	.4426	.5590	.5050	.5116	.4750	.6018	.5183	.1198	8
Hand breadth	9	.5977	.5153	.5095	.3850	.4717	.5469	.5922	.6190		.5660	.4769	.5320	.5583	.6648	.5816	.5545	.4275	.5783	.4904	.1421	9
Chest girth (xiphoid girls)	10	.7761	.4636	.4506	.3358	.4081	.4138	.4730	.4216	.4119		.7636	.7069	.7483	.6690	.6322	.7144	.3980	.6367	.5794	.3016	10
Waist girth	11	.7783	.3951	.4063	.2909	.3522	.3744	.4323	.3780	.4227	.8083		.8038	.6817	.6001	.5843	.6688	.4077	.5737	.4730	.3360	11
Hip girth	12	.8980	.5784	.6003	.4045	.4848	.4934	.4894	.4766	.5144	.7080	.7347		.6582	.5983	.6200	.6938	.5794	.5863	.5190	.3726	12
Arm girth	13	.8351	.3985	.4284	.2570	.3364	.3742	.4791	.3800	.4859	.7186	.7264	.8131		.7640	.6702	.8061	.3375	.5747	.4598	.5199	13
Wrist girth	14	.7456	.4422	.5044	.2812	.3810	.2320	.5223	.4791	.5790	.6281	.6030	.6974	.7600		.7263	.7223	.3515	.5890	.4623	.3022	14
Ankle girth	15	.7674	.4990	.5088	.3384	.3726	.5184	.5350	.4330	.5233	.5929	.5601	.7220	.7091	.7398		.7950	.3670	.5965	.4518	.3362	15
Knee girth	16	.8403	.4711	.4782	.3247	.3852	.4483	.4924	.4054	.4872	.6756	.6625	.8104	.8076	.7193	.8183		.3852	.6535	.4620	.4562	16
Inter spinous breadth	17	.5942	.4614	.4791	.4091	.3615	.4081	.3567	.3810	.3895	.4685	.5023	.5869	.4981	.4427	.4222	.4735		.5694	.4420	.1072	17
Inter trochanteric breadth	18	.8175	.6544	.5835	.4883	.5507	.5656	.5029	.5280	.5118	.6028	.6002	.8150	.6461	.6291	.6344	.6911	.3610		.5700	.2205	18
Inter Acromial breadth	19	.6213	.6100	.5840	.4650	.5410	.5360	.4630	.5543	.4982	.5179	.4899	.5595	.4696	.5088	.4367	.4657	.3705	.3707		.1046	19
Sub cutaneous fat (triceps)	20	.4876	.1052	.1145	.0599	.0934	.1186	.1722	.0749	.1395	.4151	.4598	.5302	.6326	.4040	.4801	.5759	.2628	.3799	.1670		20

GIRLS

TABLE 2A

Comparison of Results

BOYS

	5-9						7-11			10-13						14+			ALL GROUPS		
	PRIVATE SCHOOLS			FREE SCHOOLS			FREE SCHOOLS			PRIVATE SCHOOLS			FREE SCHOOLS			PRIVATE SCHOOLS					
	GEN.	I	II	GEN.	I	II	GEN.	I	II	GEN.	I	II	GEN.	I	II	GEN.	I	II	GEN.	I	II
Weight	.921	−.080	−.075	.965	−.084	.083	.945	−.135	.216	.959	−.100	−.033	.968	−.054	.048	.946	−.184	−.093	.960	−.100	−.108
Height	.795	.534	.170	.861	.392	.313	.843	.446	.347	.845	.414	.196	.861	.359	.053	.869	.386	.122	.840	.420	.096
Sitting height	.692	.231	−.070	.800	.275	−.026	.803	.288	.036	.775	.298	−.060	.774	.309	−.180	.784	.091	−.060	.777	.241	−.064
Leg length	.549	.512	.290	.740	.356	.418	.683	.414	.397	.677	.352	.269	.794	.338	.081	.686	.441	.237	.700	.400	.160
Arm length	.724	.433	.121	.787	.410	.438	.810	.388	.187	.756	.277	.313	.780	.337	.071	.782	.321	.134	.760	.360	.163
Foot length	.700	.327	−.010	.801	.290	.121	.761	.390	.034	.816	.255	−.035	.789	.387	−.077	.748	.338	−.068	.770	.320	.002
Foot breadth	.560	.028	−.323	.675	.043	−.424	.784	.103	−.238	.692	.050	−.397	.748	.126	−.267	.696	.059	−.355	.670	.060	−.274
Hand length	.698	.347	−.158	.753	.317	−.083	.806	.366	.280	.776	.353	−.062	.806	.313	−.105	.790	.285	−.039	.760	.320	−.090
Hand breadth	.693	.042	−.262	.687	.058	−.369	.754	.141	−.361	.764	.141	−.315	.769	.107	−.178	.768	.085	−.377	.729	.085	−.293
Chest girth	.786	−.231	.075	.805	−.183	.006	.866	−.178	−.114	.815	−.328	.032	.790	−.304	.155	.828	−.292	.267	.800	−.265	.057
Waist girth	.744	−.272	.145	.702	−.381	.090	.784	−.326	−.106	.773	−.389	.200	.761	−.366	.298	.746	−.322	.418	.745	−.340	.191
Hip girth	.790	−.150	.118	.794	−.251	.312	.869	−.325	.024	.920	−.210	.144	.820	−.212	.293	.814	−.172	.437	.812	−.200	.244
Upper arm girth	.720	−.584	−.061	.763	−.430	.016	.767	−.463	.081	.788	−.542	.023	.814	−.432	−.105	.741	−.486	−.005	.760	−.490	−.082
Wrist girth	.720	−.301	−.352	.758	−.306	−.274	.827	−.072	−.255	.799	−.163	−.374	.802	−.260	−.259	.807	−.161	−.325	.770	−.240	−.276
Ankle girth	.770	−.275	−.110	.760	−.252	−.177	.820	−.178	−.064	.828	−.171	−.186	.802	−.229	−.344	.747	−.262	−.498	.778	−.235	−.189
Knee girth	.802	−.366	−.012	.833	−.346	−.005	.908	−.228	.154	.831	−.406	.044	.865	−.318	−.189	.788	−.265	−.321	.827	−.340	−.071
Inter spinous breadth	.502	.200	.083	.586	.155	.042	.660	−.053	−.135	.607	.223	−.034	.636	.192	.285	.554	.073	.180	.567	.160	.115
Inter trochanteric breadth	.765	−.041	.071	.826	.107	−.061	.884	−.082	.021	.780	.078	−.044	.831	.117	.155	.813	.035	.084	.800	.070	.006
Inter acromial breadth	.493	.112	.083	.706	.130	−.230	.719	.098	−.201	.715	.078	−.088	.665	.171	−.058	.716	−.050	.142	.663	.100	−.024
Sub cutaneous fat	.366	−.468	.227	.312	−.477	.294	.604	−.607	.277	.328	−.587	.231	.440	−.516	−.009	.115	−.139	−.325	.300	−.450	.090

TABLE 2B

Comparison of Results

GIRLS

	5-9 YRS.						7-11 YRS.			10-13 YRS.						14+ YRS.			ALL GROUPS		
	PRIVATE SCHOOLS			FREE SCHOOLS			FREE SCHOOLS			PRIVATE SCHOOLS			FREE SCHOOLS			PRIVATE SCHOOLS					
	GEN.	I	II	GEN.	I	II	GEN.	I	II	GEN.	I	II	GEN.	I	II	GEN.	I	II	GEN.	I	II
Weight	.908	−.198	−.045	.959	−.084	−.190	.939	−.155	.020	.964	−.204	−.018	.956	−.110	−.088	.943	−.239	.016	.955	−.184	.017
Height	.786	.499	.099	.825	.448	.113	.812	.478	.270	.788	.488	.285	.855	.399	.111	.681	.595	.278	.797	.487	.249
Sitting height	.726	.341	−.051	.684	.303	−.116	.780	.329	.163	.765	.228	−.160	.809	.322	.002	.653	.204	.042	.723	.259	.052
Leg length	.593	.445	.093	.708	.416	.201	.648	.489	.179	.523	.494	.414	.725	.445	.179	.429	.578	.318	.629	.508	.246
Arm length	.693	.503	.123	.730	.438	.114	.730	.415	.119	.689	.472	.332	.757	.390	.174	.567	.608	.190	.692	.482	.143
Foot length	.686	.415	.110	.780	.409	.137	.784	.365	−.092	.688	.427	.009	.789	.311	.151	.632	.421	.057	.731	.427	.084
Foot breadth	.590	.208	−.092	.638	.131	−.044	.735	.096	−.229	.681	.168	−.197	.700	.073	−.075	.625	.013	.256	.642	.094	−.183
Hand length	.647	.477	−.113	.743	.440	−.048	.744	.462	−.127	.770	.425	−.032	.765	.347	−.054	.583	.550	−.136	.709	.448	−.120
Hand breadth	.621	.205	−.050	.725	.118	−.106	.766	.185	−.343	.602	.153	−.401	.781	.180	−.170	.621	.151	−.297	.673	.173	−.254
Chest Girth	.731	−.312	−.191	.768	−.231	−.221	.753	−.285	−.068	.783	−.291	−.071	.805	−.280	−.059	.696	−.237	−.199	.751	−.260	−.140
Waist girth	.703	−.330	−.263	.660	−.355	−.266	.780	−.361	−.091	.773	−.391	−.058	.787	−.338	−.185	.718	−.360	−.189	.732	−.340	−.179
Hip girth	.903	−.330	−.030	.823	−.257	−.054	.910	−.307	.149	.903	−.309	.002	.909	−.183	−.017	.813	−.241	.078	.879	−.294	.081
Upper arm girth	.841	−.405	−.035	.738	−.502	.003	.759	−.477	−.071	.824	−.405	.089	.829	−.432	.045	.725	−.552	.076	.798	−.455	−.035
Wrist girth	.736	−.254	−.063	.748	−.362	−.005	.785	−.119	−.179	.773	−.157	−.158	.842	−.230	−.008	.740	−.164	−.128	.778	−.231	−.099
Ankle girth	.745	−.282	.253	.763	−.194	.307	.834	−.260	−.083	.831	−.176	.018	.809	−.272	.199	.735	−.280	.090	.779	−.232	.104
Knee girth	.743	−.413	.196	.777	−.334	.284	.865	−.294	.000	.874	−.339	.043	.877	−.323	.139	.756	−.460	.163	.812	−.368	.136
Inter spinous breadth	.610	−.113	−.108	.684	−.054	−.219	.645	−.076	.085	.561	−.026	−.066	.696	−.077	−.355	.529	−.060	−.096	.611	−.054	.000
Inter trochanteric breadth	.804	−.076	.023	.829	.030	.042	.867	−.148	.238	.890	−.133	−.061	.855	.070	−.118	.820	−.161	−.018	.830	−.073	−.084
Inter acromial breadth	.692	.208	−.260	.680	.268	−.063	.695	.308	.038	.747	.053	−.066	.767	.172	−.100	.565	.224	−.189	.687	.147	−.211
Sub cutaneous fat	.444	−.532	.142	.342	−.558	.130	.564	−.626	.062	.517	−.588	.233	.418	−.533	.177	.436	−.476	.256	.422	−.525	.363

TABLE 3

Comparison of Results From Two Studies

American Children's Clothing Survey and English 7–11 year group

	General factor		Type factor	
Boys	English	American	English	American
Weight	.953	.965	—.107	—.109
Height	.805	.826	.431	.266
Sitting height	.789		.347	
Vert. trunk girth		.899		.067
Tibial height		.728		.543
Crotch length		.830		.012
Leg length	.757	.735	.333	.546
Arm "	.781	.777	.386	.350
Foot "	.739		.381	
Hand "	.781		.389	
Foot breadth	.785		.186	
Hand "	.732		.286	
Wrist "	.773		.266	
Elbow "	.800		.107	
Ankle "	.784		—.138	
Knee "	.878		—.085	
Interspinous breadth	.653		—.023	
Intertrochanteric "	.899	.902	—.044	—.095
Interiliac "	.769		—.077	
Inter acromial "	.716		.155	
Chest breadth	.691		—.088	
Chest depth	.671		—.050	
Neck base girth		.732		—.002
Chest "	.880	.881	—.178	—.187
Waist "	.800	.802	—.303	—.330
Hip "	.879		—.303	
Seat "	.909	.948	—.275	—.212
Upper arm "	.796	.819	—.378	—.348
Armscye "		.847		—.113
Wrist "	.842		.055	
Ankle "	.857		—.138	
Knee "	.923	.880	—.187	—.006
Calf "	.873	.862	—.208	—.130
Thigh "		.864		—.306
Body fat	537		—.582	

next factor is not equivalent since it is based largely on the division of breadths which are not present in the American study.[3] The comparison is between two batteries of correlations in which age has been eliminated, in one case by partial correlation (holding age constant), in the other by correlating deviations about the yearly averages. Agreement with the analysis of the American zero order correlations (in which age is retained) is almost as good, the difference being that the general factor contributes a greater proportion of the total variance as it now includes the size differences between ages as well as within age groups. The type factor is little affected.

NATURE OF THE FACTORS

To some extent the initial choice of measurements determines the types that will result, hence a fairly representative set of body measurements was used, especially in Group B where additional breadths were included to counteract the slight preponderance of girths in the other groups. The results actually differ little from those of the smaller battery.

The three main factors were as follows:

The general factor for physical size: indicating a general tendency to be above or below average for age in all measurements. As one might expect, weight was the best indicator of general size and subcutaneous tissue the least indicative. This factor accounted for some 56% of the total variance. Weight was so highly correlated with the pool of all the measurements that it could quite reliably be used as a substitute for most purposes.

Type factor: Pachysome-leptosome dichotomy. After eliminating general size, the first type factor showed that the measurements were grouped quite clearly and regularly into length and circumferential measures with breadth measurements aligned with the lengths. Children excelling in the length measurements will, therefore, be the leptosomes and those excelling in girths and fat, pachysomes, to use Burt's term (Burt, '47). The best indicators of the length group were stature and leg length for both girls and boys and the circumferential component was most clearly indicated by upper arm circumference, knee circumference and subcutaneous fat in both groups. The factor variance was 10% of the total variance.

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[3] The closeness of the comparison suggests the interesting possibility of devising standard batteries consisting of a representative set of measurements (e.g. for head or general body dimensions—possibly obtained from pooled batteries) in which the general factor saturations are accepted for use in studying finer relations between groups of measurements which are themselves too specialised to produce a general factor for body measurements—as distinct from their own common factor. As an example, Table 3 shows that where measurements are common to both groups the general factor saturations could be taken from either study and one could probably also pool the remaining figures, so producing the equivalent of a battery of some 40 measurements.

In the American study where somewhat different girth and length measurements were used, the distinction into vertical measurements and girths is without exception, and weight is again grouped with the girths. Only one breadth measurement was included.

Factor for trunk-limb development. The second type factor is not as clearly defined as the first. For girls it shows up in a tendency to develop the trunk (lengths, breadths or girths) or the limbs (leg and arm lengths and girths with stature and foot measurements). For boys the girth development is largely due to fleshy parts (waist, hip, upper arm and body fat) with small bone formation (extremities, wrist, ankle and shoulder breadth) on one hand, or large breadth of trunk and limb bones on the other. The pachysome type can therefore be split into the pyknics who are rotund but not broad and the eurysomes who are broad and stocky rather than plump. The growth in length results either in long, slender limbs and short trunk or long trunk and shorter and sturdier limbs.

By analysing only length and breadth measurements or only breadth and girth measurements it appeared likely that a breadth factor was present which was being overshadowed by the girth-length type factor and it was then showing itself in the secondary type factor distinguishing between pyknics and eurysomes in boys. In girls we see that the secondary type factor corresponds to trunk or limb development without differentiating between breadths and girths and indeed a group factor analysis of 33 measurements for Group B girls which included 6 lengths, 11 breadths and 10 girths failed to give any factor corresponding to breadth measurements. The bi-polar analysis of the larger battery differentiated between the lengths on one hand and trunk girths and breadths on the other, with limb breadths following the limb and other lengths. Shoulder breadth and knee breadth were the exceptions.

Interpretation of the first type factor.

When we examine the saturation coefficients more closely they suggest the interesting possibility that the physical types may be related to the degree of maturation and sex differentiation. If we consider the female form in relation to the measurements we have girths (especially those which include fat) predominating over the length and skeletal measurements and with large hip measurements especially characteristic. Conversely the male form has large bone size—especially of the long bones—breadth of shoulders but not of hips, and low fat measurements and girths over fatty regions. Knee is one of the girths in which girls excel (even in absolute measurements). These results are consistent with the leptosome type being on the whole more masculine and the pyknic type more feminine.[4] We should then expect shoulder breadth to be in the opposite group from the trunk and pelvic development, whilst knee breadth as well as girth would go with the more "feminine" component, and this is so.

The fact that ankle, wrist and elbow breadths are grouped apart from the correspondingly named girths is due to the location of the breadths being at the condyles of bones whereas the girths are taken at the "waist" position so avoiding these prominences but including fat and also muscle near its point of attachment. They are fundamentally different measurements and the analysis shows this. Another possible interpretation of the first type grouping is the distinction between essentially bony and non-bony measurements, but this is open to the objection that trunk breadths and depths, as measured from the location of bony points, are grouped with the corresponding girths which include the other tissues as well.

ASSESSMENT OF THE INDIVIDUAL'S TYPE STRENGTH AND ITS CONSTANCY OVER THREE YEARS

Besides knowing what physical types exist in the sample, we need to know which individuals fall into the different types and also whether they are extreme examples or not. The most satisfactory way to measure a child's type strength is by means of regression equations which weight the measurements according to their diagnostic value as type determiners.

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[4] Some justification for this is given by the fact that Berry and Cowin ('51) found (male) pubic development to be more advanced among the leptosomes than among the pyknics. In Table 3 they show that successive stages of pubic development are accompanied by progressively more leptosome habitus (greatest height for given weight and reduced subcutaneous fat). The author's statement in the discussion that "pyknics tend to mature more rapidly than leptosomes" is quoted from an unsubstantiated observation in "Child Health and Development," p. 173, Ed. Ellis Churchill, 1947, and it is at variance with their own results.

The general and first type factor values for each child have been calculated from regression equations involving all 20 measurements taken;[5] these are the values on which the type classification is based. Shorter methods of typing have been studied and the results of the agreement with the long method are given below. The constancy of individual type values over two or three years expressed as the correlations between first and second measurements were of the order 0.80 (0.65–0.92) for boys and girls; the correlations tending to be lower around puberty. This means that, for the leptosome-pyknic type division, after the three years interval when the children were re-measured, some 11% of the boys then aged up to 13 years had changed their type, whilst after age 14, 18% were found to have changed their type. For girls the percentages were 8% up to age 9 years, 22% for girls who had reached 10–13 years and after 14 years the figure again fell to 12%. Most of the children who changed their type were in the intermediate range on both occasions but in some cases considerable change occurred when certain of the boys tended to increase their heights and limb lengths without "filling out" correspondingly, or a few failed to gain much in height but continued to gain in girth measurements. For the girls the marked changes nearly always consisted of a great increase in girth and fat measurements compared with the group. These results can most readily be interpreted as being due to a different time of onset of the pubertal spurts. The type changes were not associated with any change in the nutritional gradings, though it is conceivable that the clinician might have altered his assessments in some cases had he known the previous conditions of the children.

Simplified type measurements.

From a practical point of view there is need for an accurate easily applied scheme of typing based on a few measurements only.

One method is to retain only those measurements with high coefficients in the regression equations. When many measurements are discarded the remainder will have different coefficients and their diagnostic importance may be altered, but this can be calculated. However, in the case of the general factor for body size, weight alone has such a preponderant effect that a satisfactory approximation can be obtained by relying on weight alone (the general factor saturations for weight vary from 0.91 to 0.97). On applying this method to the estimation of the type factor, the highest multiple correlation was obtained using height and arm length, arm and knee girths. ($R_m = 0.947$). The equation being as follows:

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[5] Mean measurements for the types have been calculated separately for each year of age, the sexes and the different school groups in order to study the relation between physical type and the assessments of nutritional status, the effect on growth and also the effect on the prediction of body weight from certain measurements. It is hoped to publish these findings in another paper.

$$\text{type} = .226 \text{ height} + .135 \text{ arm length} - .227 \text{ arm girth} - .134 \text{ knee girth}$$

(where the measurements are expressed as deviations divided by the standard deviations).

Similarly the factor measurement for the leptosome-eurysome type is given by the regression equation:

$$\text{type} = .311 \text{ height} + .120 \text{ arm length} - .126 \text{ interacromium} - .073 \text{ intertrochanter},$$

(a plus score indicating leptosome and a minus score eurysome type).

For the pyknic-eurysome type the equation is as follows:

$$\text{type} = .119 \text{ interspinous} + .141 \text{ intertrochanter} + .137 \text{ interacromium} - .203 \text{ arm girth} - .228 \text{ fat over triceps}$$

(where a positive result indicates eurysome and a negative one pyknic type).

The multiple correlations are 0.92 for the leptosome-eurysome distinction and 0.75 for the pyknic-eurysome distinction. ($R_m = 0.72$ is given by trochanter, acromium and arm girth alone).

Even with only 4 or 5 measurements, regression equations are rather cumbersome since they require different weights for each sex and age and possibly also social group, to allow for their different means and standard deviations. An alternative simplification is to use the ratio of measurements indicating opposite type tendencies. With children there is always the difficulty that age has to be allowed for, and the usefulness of a ratio is greatly increased if it does not vary from age to age. The most serious difficulty about ratios is that the denominator and numerator must be made comparable by adjusting for differences in the size of the standard deviations.[6]

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[6] Two simple tests of whether measurements can justifiably be used in a direct ratio are: (1) do the means remain at the same proportion throughout the age range?; (2) are the coefficients of variation the same? The standard deviation is

In a trial group of 6 year old boys where the standard deviations of height and weight were numerically equal, a ratio of weight/height (with a constant to allow for different means so centering the ratio at 1.00) gave a correlation of 0.86 with the actual factor measurements. The determination of the constant required to maximize the correlation is probably worth while, though no *simple* relation of height and weight can be used at all ages in view of the different relations between the standard deviations at different ages.

Another ratio of measurements of opposite type value (which, moreover, changes little with age, being approximately 2 : 1 for boys and 2.1–2.2 for girls) is that of height/chest. The other very useful property is that the ratio of the standard deviations of the two measurements is also fairly constant at practically the same ratio. This means that type could be indicated by the straightforward ratio $\frac{\text{height cms} \times 100}{2 \times \text{chest cms}}$ and it will tend to center near 100 and be free from any bias introduced by non-comparable units. However, absolute figures should only be compared within the same age group.

The correlation between the $\frac{\text{height}}{2 \times \text{chest}}$ ratio and type factor measurement was 0.66 in a 6-year boys group and 0.73 in a girls 10-year group. (Corresponding multiple correlations of type with height and chest are 0.73 and 0.75). The rank order correlation between original ratio value and that for three years later is 0.82 for the boys and 0.70 for the girls. (This is over the pubertal ages 10-13 where one would expect most irregularity of growth).

Another ratio based on measurements having a fairly constant relation to each other and whose standard deviations are also roughly proportional to the means, is that of height and hip girth. The correlation with type is 0.83 for girls with a reliability coefficient between first value and one three years later = 0.66. (The multiple correlation of type with height and hip girth is 0.79.)

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the equivalent unit of measurement and, therefore, if a child is above or below average by one standard deviation in either measurement this should result in the same change of value for the ratio, otherwise a bias is being introduced in favor of one or other measurement and big children will tend to have different ratios from small ones (this assumes that the variables are distributed approximately normally). If comparisons are being made within a restricted age or size range (1) above is no longer necessary. According to these criteria the ratios for slender-stocky body form in children (Meredith and Culp, '51) and Pryor's ('43) width-weight tables are of variable usefulness.

The ratios would seem to answer the purpose of providing a simple type assessment fairly satisfactorily, but they should be used with discrimination especially when approaching the pubertal age.

DISCUSSION

As we have seen, the results of analyzing measurements of children show that physical types corresponding closely to the leptosome—pyknic differences in adults can already be differentiated at 5 years onwards. Moreover, they remain fairly constant throughout childhood. This may indicate that there is a constitutional basis which determines the future development. On the other hand the fact that an individual has a certain body build at, say, age 8 years may indicate that he is likely to remain of the same type throughout childhood simply because his growth (which is predominantly an all-round function affecting all bodily structures rather than being specific to particular organs) will not be sufficiently varied to erase the pattern of his present measurements. This situation obtains at least until puberty and probably through it, because even the apparently marked difference in shape which arises during puberty is not comparable with the overall increase in growth (which is also at its maximum).

Analysis of the individual's growth increments in different measurements is needed to determine the extent to which general growth and " directional " or type growth predominate and in the author's unpublished studies the general *growth* factor contributed 43% of the total growth variance compared with type growth (i. e. length growth compared with breadth or girth growth) of 8% for babies' growth from one to 5 years. For schoolchildren the variance of growth common to all measurements was 40% of the total growth variance, and the residual variance would include all growth which was specific to separate structures (including error variance), growth of related parts, e. g. hand length and breadth, as well as the type growth.

When the adult stage is reached the situation is quite different because growth ceases but weight may continue to increase up to or after middle age, followed by a loss in weight as reserves are used up without replacement. Here the weight change is mainly responsible for change in fat and girth measurements without affecting lengths; hence differences in the amount of change affect body build. The nearest comparable influence in childhood is the effect of nutritional conditions which, besides depressing or accelerating growth, also cause specific change in body fat—and consequent change of the girths—either through increasing it as a storage product when intake exceeds the energy needs of growth and activity, or decreasing it as the balance is reversed.

The leptosome-pyknic type values are affected by sex, age, nutritional conditions and social class among others, and the simplest way to allow for these conditions is to regard the measurements as being relative to the sex, age and social class within the nutritionally normal or subnormal levels.

Only when one can be assured that the varieties of physique can be measured satisfactorily can one begin to assess their effects on growth, susceptibility to disease, and in the wider psychosomatic field.

SUMMARY

The present paper has shown that after allowing for general size differences, types similar to the leptosomes, pyknics and eurysomes in adults can be distinguished in children from ages 5–18 years. The major type division proved very constant from one group to another.

The distinction is made between pyknics and eurysomes rather than mesosomes and eurysomes because neither of these types is intermediate but instead one excels in breadth of trunk (having a flattened cross-section) and the other in all-round girth (having a more cylindrical cross-section).

Secondary types corresponding to those with large trunk and small limbs and the converse also exist, but this distinction accounts for very little of the total variance. It is suggested that type differentiation is related to degree of maturation and sex differentiation in boys, pyknics having relatively infantile characteristics and later public development than leptosomes.

Regression equations and ratios of diagnostic measurements have been tested against type factor measurements based on all 20 variables and these would seem to provide effective short cut methods of typing.

Children were remeasured after an interval of three years and the constancy of type was high. This was due not so much to continuing to develop along characteristically type lines but because growth is mainly general or isometric and therefore fails to upset the type pattern once formed. These considerations are fundamentally different from the ones affecting type constancy in adults.

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INCREASE IN CRANIAL THICKNESS DURING GROWTH*

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INTRODUCTION AND MATERIAL

FOR many years, anthropologists have studied cranial thickness in different racial groups but no attention has been paid to the increase in cranial thickness as individuals grow. In fact, I can find only two reports in the literature of studies on skeletal material of known age and neither of these is comparable to the present study.

In 1882, Anderson reported measurements of cranial thickness in 154 Irish cadavers. The age at death was known in the majority of these but only 4 of the group are in the age range which is covered by the present material. Furthermore, Anderson made his measurements at points which are not precisely defined so that no useful comparison can be made between his findings and those presented here.

There are satisfactory data available regarding cranial thickness in the white American male between the ages of 20 and 84 years. These were published by Todd ('24) following a study of 484 skulls of known age and should be regarded as an extension of the findings which are recorded in this paper.

The measurements presented here were made on the radiographs of children examined between the ages of three months and 17 years. During the first year, these examinations were at three-month intervals. Between 1–5 years examinations were made at intervals of 6 months. Annual examinations were made thereafter until the age of 21. These radiographs were all taken under standardized conditions using the Bolton-Broadbent cephalometer (Broadbent, '31) and the measurements

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made on them have all been corrected for the known amount of enlargement that occurs.

Measurements have been made on a total of 32 white American children of whom 14 were boys and 18 were girls and all of whom attended every examination referred to above. It was considered desirable to extend the study beyond 17 years, but since none of these children had been serially examined beyond this age, measurements were made on the isolated radiographs of subjects who were of the same sex and race as the previous group. In this way, the study was extended to 21 years. In the graphs, those studied up to the age of 17 years are referred to as "Group I" while those studied between the ages of 18 and 21 years are referred to as "Group II." The health records of all the children were available and no child who had had a serious illness was included.

METHOD

Tests were made with dried skulls to be certain that the landmarks used could be accurately located on the radiographs. It was further determined that measurements made on the dried skull were equal to corrected ones made on its matching radiograph. All the radiographic measurements were made with sharp pointed dividers at right angles to a tangent to the image of the ectocranial margin. After comparison with a scale, measurements were recorded in tenths of a millimeter.

Lateral views were available throughout the whole of the period studied but after the child was about 4 years old the cranial outline did not completely fit on the film and so its thickness could not be measured at the vertex. Fortunately the frontal views were usually taken from three years onwards so there is no lack of continuity in the measurements of thickness at vertex. In some cases, this measurement could be made on both lateral and frontal radiographs and it was noted that there was no difference in the findings.

DISCUSSION OF FINDINGS

Nasion: After a variable age the frontal sinus grows across the plane in which this measurement was made. Following this change the width of the sinus was measured in the same plane and subtracted from the total thickness. In this way, two values were obtained which have been recorded as "total thickness" and "bone thickness only." The age at which the frontal sinus first extended to this level is recorded in table 1. It will be noted that there is no significant sex difference in the average age but that there is a wide individual variation in both sexes.

TABLE 1

The age in years at which the frontal sinus extends superior to the plane of measurement at nasion

	MALES	FEMALES
Average	6.6	7.0
Standard deviation	2.5	2.0
Oldest	12.0	11.0
Youngest	3.5	3.5

In table 2 and figure 1 the observations regarding total thickness at nasion in both males and females are presented. While the graphs for both sex groups generally run parallel it will be seen that the male figures are generally 8–11 per cent in excess of the female measurements at the same age. In both groups, the rate of increase is less rapid after one and one-half years but the male group does continue to increase slowly throughout the 17-year study period whereas the female group reaches its 17-year old thickness at 15 years.

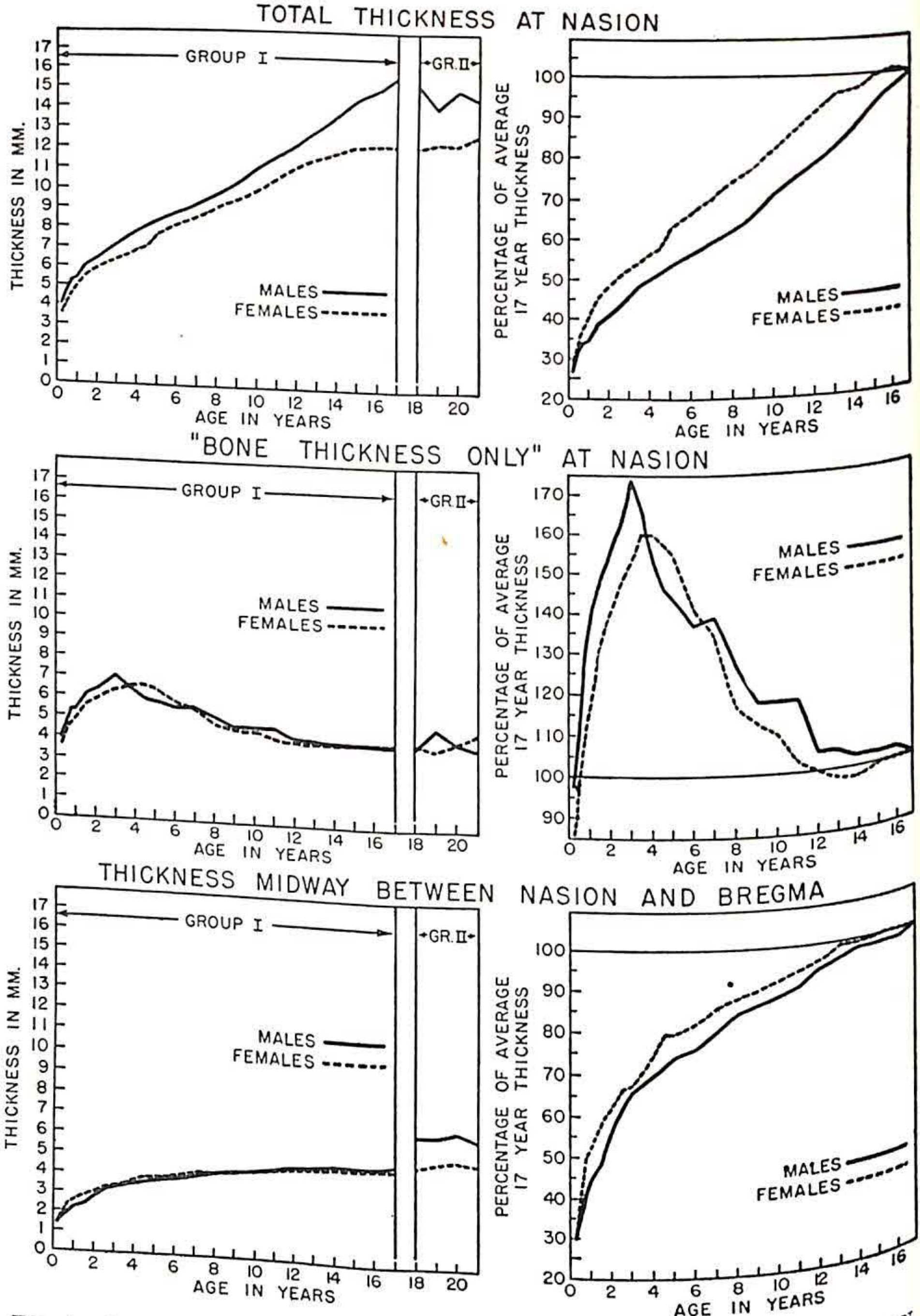
TABLE 2

Total thickness at nasion recorded in millimeters

AGE IN YEARS

		¼	½	¾	1	1½	2	2½	3	3½	4	4½	5	6	7
MALES	Mean	4.0	4.7	5.3	5.4	6.1	6.4	6.7	7.1	7.6	7.8	8.1	8.4	8.8	9.3
	S. D.	0.4	0.6	0.2	0.5	0.2	0.4	0.7	0.9	0.9	1.2	1.0	0.9	1.3	1.5
FEMALES	Mean	3.6	4.2	4.6	4.9	5.6	5.9	6.2	6.4	6.6	6.9	7.1	7.7	8.2	8.6
	S. D.	0.3	0.4	0.5	0.6	0.5	0.6	0.6	0.5	0.5	0.6	0.6	0.6	0.9	0.9

		8	9	10	11	12	13	14	15	16	17	18	19	20	21
MALES	Mean	9.8	10.3	11.1	11.7	12.2	12.9	13.6	14.5	15.0	15.6	15.3	14.1	15.0	14.5
	S. D.	1.8	1.7	1.8	1.8	2.4	2.3	2.4	2.5	2.4	2.6	2.4	2.6	2.7	2.9
FEMALES	Mean	9.1	9.5	10.0	10.6	11.2	11.6	11.8	12.2	12.3	12.2	12.2	12.4	12.3	12.8
	S. D.	0.9	1.1	0.9	0.8	1.1	1.0	1.0	1.0	1.0	0.8	1.2	1.3	1.3	1.4



TOTAL THICKNESS AT NASION

"BONE THICKNESS ONLY" AT NASION

THICKNESS MIDWAY BETWEEN NASION AND BREGMA

FIG. 1. GRAPHS SHOWING ABSOLUTE AND RELATIVE SKULL THICKNESS AT NASION AND AT A POINT MIDWAY BETWEEN NASION AND BREGMA.

In figure 1 the findings in both males and females have also been presented as percentages of the total thickness at 17 years. The female group is in advance of the male group at all ages and after the age of 4 years the female group attains any specified percentage of this thickness two to three years in advance of the male group.

It will be seen that between three and 14 years this thickness gradually declines in the males and then remains constant in the group of children serially examined. Essentially, the same pattern is seen in the female group and it should be noted that in both groups the "bone thickness only," during adolescence and early childhood, is approximately the same as it is during the first year of life. Table 3 and figure 1 show the findings regarding "bone thickness only" at nasion. After a comparison of the graphs showing "total thickness" and "bone thickness only" it will be realized that the width of the sinus increases after the age of 12 years but that the rate of increase during this period is not sufficiently rapid to reduce the amount of bone already present. In figure 1 the average measurements of "bone thickness only" are also presented as percentages of the average "bone thickness only" at 17 years. In this graph it becomes very clear that in both sexes there is a rapid relative increase between birth and three years, after which there is a rapid decrease until 12 years when the 17-year old thickness is

TABLE 3

Bone thickness only at nasion recorded in millimeters

		AGE IN YEARS																											
		¼	½	¾	1	1½	2	2½	3	3½	4	4½	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
MALES	Mean	4.0	4.7	5.3	5.4	6.1	6.4	6.7	7.1	6.8	6.3	6.0	5.9	5.6	5.7	5.2	4.8	4.8	4.8	4.3	4.3	4.2	4.2	4.2	4.1	4.0	5.0	4.3	4.0
	S. D.	0.4	0.6	0.2	0.5	0.2	0.4	0.7	0.9	0.5	1.0	1.1	1.2	1.1	1.2	1.4	1.3	1.2	1.8	1.0	1.1	1.0	0.9	1.1	1.0	1.1	1.2	1.1	0.9
FEMALES	Mean	3.6	4.2	4.6	4.9	5.6	5.9	6.2	6.4	6.5	6.7	6.6	6.5	5.9	5.6	4.9	4.7	4.6	4.3	4.2	4.1	4.1	4.2	4.2	4.2	4.2	4.0	4.3	4.8
	S. D.	0.3	0.4	0.5	0.6	0.5	0.6	0.6	0.5	0.5	0.7	0.6	1.1	1.8	1.6	1.5	0.8	0.6	0.4	0.6	0.5	0.5	0.5	0.5	0.5	0.6	0.5	0.6	0.6

usually established in both sexes. It should be noted that both in males and females the thickness at 17 years is equal to the thickness during the first 6 months of life.

Midway Between Nasion and Bregma: Measurements were made at the point where a perpendicular through the midpoint of a line joining nasion to bregma crossed the external outline of the skull. The findings are recorded in table 4 and figure 1, where it will be seen that these findings are very similar in the two sexes. Increase in thickness is very slow after the age of 5 years but is still occurring up to the end of the period during which the measurements were made on children examined serially. The group added, in order to prolong the study to 21 years, shows a greater skull thickness at this point than the original group.

TABLE 4

Skull thickness in millimeters midway between nasion and bregma

AGE IN YEARS

		¼	½	¾	1	1½	2	2½	3	3½	4	4½	5	6	7
MALES	Mean	1.5	1.8	2.0	2.2	2.4	2.8	3.1	3.3	3.4	3.5	3.6	3.7	3.8	4.0
	S. D.	0.2	0.3	0.3	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.3	0.5	0.5	0.4
FEMALES	Mean	1.4	1.9	2.4	2.5	2.8	3.0	3.2	3.3	3.4	3.6	3.8	3.8	3.9	4.1
	S. D.	0.3	0.4	0.5	0.6	0.4	0.5	0.5	0.5	0.4	0.6	0.6	0.7	0.7	0.8

		8	9	10	11	12	13	14	15	16	17	18	19	20	21
MALES	Mean	4.2	4.3	4.4	4.5	4.7	4.8	4.9	4.9	4.9	5.0	6.6	6.6	6.8	6.4
	S. D.	0.5	0.5	0.5	0.6	0.6	0.5	0.6	0.7	0.6	0.8	1.4	1.3	1.0	1.1
FEMALES	Mean	4.2	4.3	4.4	4.5	4.6	4.7	4.7	4.8	4.8	4.8	5.0	5.2	5.4	5.2
	S. D.	0.8	1.0	1.0	1.0	0.9	0.9	1.0	1.0	1.1	1.0	1.1	1.2	1.2	1.3

The findings have also been presented in a relative fashion and it can be seen that at all ages the average of the female group is a higher percentage of the average 17-year old thickness than is the male average.

Bregma: Unfortunately, the measurements at bregma are very incomplete. After the males reach the age of 4 years and the females reach 9 years the cranial thickness could not be measured at this point on the radiographs of all the members of the group. This is due to the fact that the cranial outline became too large to fit the size of film used.

The findings are presented in table 5 and figure 2 and in these it will be seen that there is no sex difference over the period during which both males and females could be examined. The increase in thickness is rather rapid until the age of 4 years and then its rate gradually declines in the female group, which alone could be followed for a longer period.

TABLE 5

Skull thickness at bregma recorded in millimeters

AGE IN YEARS

	¼	½	¾	1	1½	2	2½	3	3½	4	4½	5	6	7	8	9
MALES																
Mean	0.0	0.1	0.4	1.0	1.7	2.3	2.8	3.1	3.3	3.5	—	—	—	—	—	—
S. D.	0.0	0.1	0.1	0.2	0.5	0.6	0.7	0.4	0.5	0.5	—	—	—	—	—	—
FEMALES																
Mean	0.0	0.2	0.5	0.7	1.5	2.1	2.6	2.8	3.0	3.1	3.2	3.3	3.4	3.6	3.7	4.0
S. D.	0.0	0.1	0.2	0.2	0.3	0.2	0.4	0.3	0.4	0.3	0.3	0.3	0.4	0.5	0.5	0.6

Vertex: In table 6 and figure 2 the findings regarding cranial thickness at vertex are presented. These have been obtained partly from the lateral and partly from the frontal radiographs. It will be seen that in

TABLE 6

Thickness of the skull at vertex recorded in millimeters

AGE IN YEARS

		¼	½	¾	1	1½	2	2½	3	3½	4	4½	5	6	7
MALES	Mean	1.0	1.4	1.8	2.0	2.4	2.7	3.0	3.3	3.5	4.0	4.1	4.2	4.4	4.6
	S. D.	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.1	0.2	0.2	0.3	0.4	0.3
FEMALES	Mean	1.1	1.4	1.7	2.0	2.4	2.7	3.0	3.3	3.6	3.7	3.9	4.0	4.2	4.4
	S. D.	0.1	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.6	0.7	0.7	0.6	0.6	0.6

		8	9	10	11	12	13	14	15	16	17	18	19	20	21
MALES	Mean	4.7	4.8	4.9	5.1	5.2	5.3	5.4	5.4	5.5	5.5	6.3	6.4	6.7	6.0
	S. D.	0.4	0.3	0.3	0.3	0.4	0.5	0.4	0.4	0.4	0.5	0.6	0.7	0.6	0.4
FEMALES	Mean	4.5	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.3	5.4	5.9	5.9	6.2	6.3
	S. D.	0.7	0.6	0.6	0.8	0.8	0.7	0.7	0.7	0.8	0.9	1.0	0.9	1.1	1.2

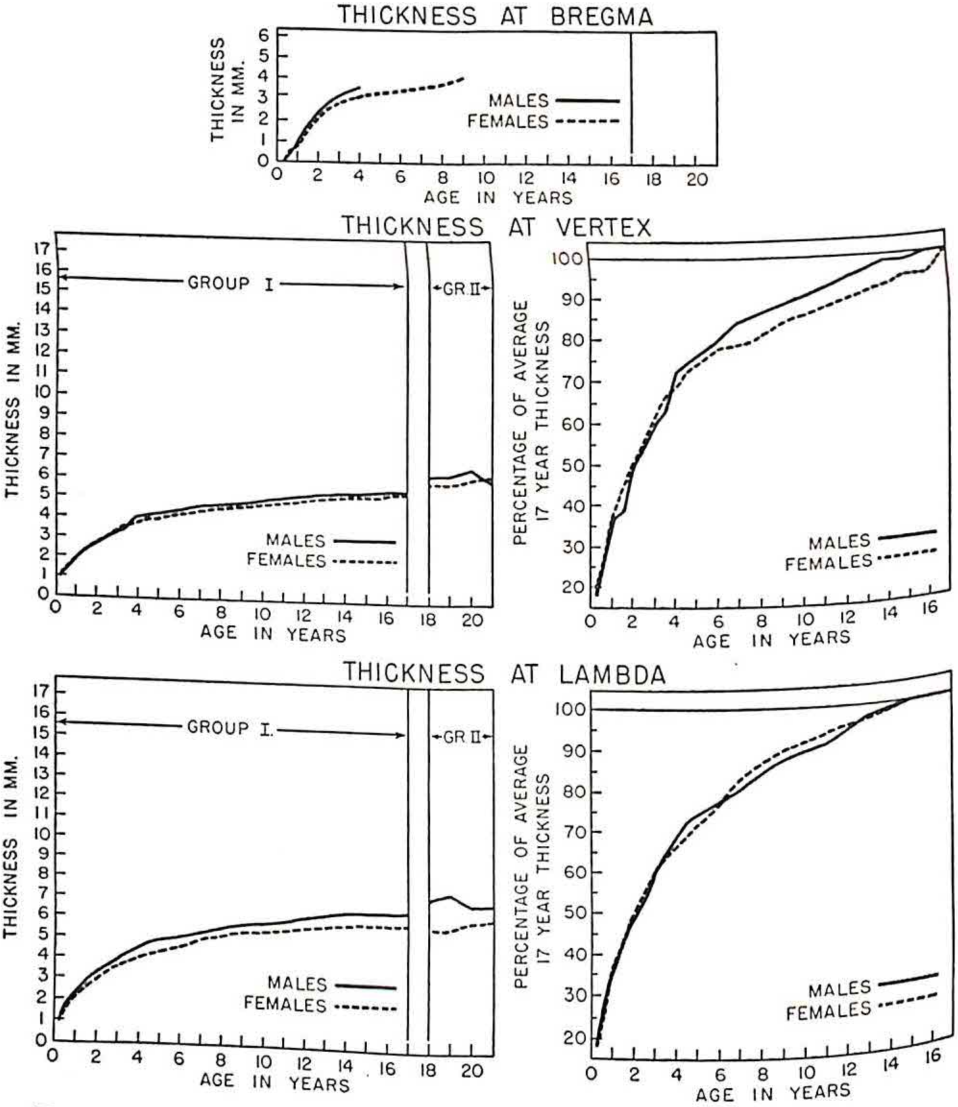


FIG. 2. GRAPHS SHOWING ABSOLUTE AND RELATIVE SKULL THICKNESS AT BREGMA, VERTEX AND LAMBDA.

both sexes there is a rapid increase until the age of 4–5 years and then a much more gradual increase until 17 years. The older group on whom measurements were made between 18 and 21 years shows a greater skull thickness than the younger group at this point also.

In figure 2 the findings at vertex have been graphed in a relative fashion and it can be seen that there is no sex difference until the age of 4 years after which the male group average reaches a higher percentage of the 17-year old average thickness at any age than does the female group.

Lambda: The findings at lambda in both males and females are recorded in table 7 and figure 2. On an inspection of these, it will be noted that the cranial thickness at this point increases throughout the period studied but that the rate of increase becomes progressively less as age advances. By the age of 7 years the cranium has attained about 80–85% of its adult thickness at lambda in both males and females. There is no difference between the findings in the two sexes when they are recorded in a relative fashion.

TABLE 7

Skull thickness at lambda recorded in millimeters

AGE IN YEARS

		¼	½	¾	1	1½	2	2½	3	3½	4	4½	5	6	7
MALES	Mean	1.2	1.7	2.0	2.3	2.9	3.2	3.5	3.9	4.3	4.5	4.8	4.9	5.1	5.3
	S. D.	0.2	0.3	0.2	0.3	0.3	0.4	0.4	0.5	0.4	0.4	0.4	0.5	0.5	0.4
FEMALES	Mean	1.1	1.5	1.8	2.2	2.6	3.0	3.3	3.6	3.8	4.0	4.1	4.3	4.6	5.0
	S. D.	0.1	0.1	0.2	0.2	0.4	0.3	0.4	0.5	0.5	0.6	0.5	0.7	0.6	0.6

		8	9	10	11	12	13	14	15	16	17	18	19	20	21
MALES	Mean	5.6	5.8	5.9	6.0	6.2	6.4	6.5	6.6	6.6	6.6	7.3	7.6	7.0	7.0
	S. D.	0.5	0.5	0.7	0.9	0.9	1.0	1.0	0.9	1.1	1.0	1.1	1.1	1.0	1.0
FEMALES	Mean	5.2	5.4	5.5	5.6	5.7	5.8	5.9	6.0	6.0	6.0	5.9	5.9	6.2	6.3
	S. D.	0.7	0.6	0.6	0.6	0.6	0.6	0.7	0.6	0.7	0.6	0.8	0.9	1.0	1.0

Euryon: This measurement of cranial thickness was made at the most lateral point of the cranial outline in the frontal view and consequently information is only available for that period during which frontal views were regularly taken. The findings are recorded in tables 8 and 9 and in figure 3, where it will be seen that there is very little lateral difference. It will be noted, however, that at all examinations the average thickness of this point in the female group is slightly greater than

TABLE 8

Thickness of skull at right euryon recorded in millimeters

AGE IN YEARS

		3	3½	4	4½	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
MALES	Mean	—	1.9	2.0	2.1	2.1	2.2	2.2	2.2	2.3	2.4	2.5	2.6	2.6	2.6	2.7	2.7	2.7	2.6	3.0	2.9	2.9
	S. D.	—	0.4	0.3	0.3	0.4	0.5	0.3	0.3	0.3	0.3	0.4	0.5	0.3	0.2	0.3	0.3	0.4	0.3	0.4	0.4	0.4
FEMALES	Mean	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.4	2.5	2.6	2.7	2.7	2.8	2.8	2.8	2.9	2.8	3.0	3.0	3.0	2.8
	S. D.	0.3	0.3	0.4	0.3	0.4	0.4	0.5	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.5	0.5	0.6	0.6	0.9	0.7	1.1

TABLE 9

Thickness of skull at left euryon recorded in millimeters

AGE IN YEARS

		3	3½	4	4½	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
MALES	Mean	—	1.8	1.9	2.0	2.1	2.1	2.2	2.3	2.4	2.4	2.5	2.6	2.6	2.6	2.6	2.7	2.7	2.8	3.3	3.1	3.0
	S. D.	—	0.5	0.5	0.4	0.5	0.4	0.4	0.3	0.5	0.5	0.2	0.3	0.2	0.2	0.2	0.3	0.4	0.4	0.6	0.4	0.3
FEMALES	Mean	1.7	1.8	2.0	2.2	2.3	2.4	2.5	2.6	2.6	2.7	2.8	2.9	2.9	2.9	2.9	2.9	2.9	3.2	3.2	3.2	2.9
	S. D.	0.4	0.4	0.3	0.4	0.4	0.5	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.5	0.6	0.5	0.7	0.8	0.7	1.1

that of the corresponding point in the male group of the same age. At no other point where the cranium was measured did the average for the female group regularly exceed that for the male group.

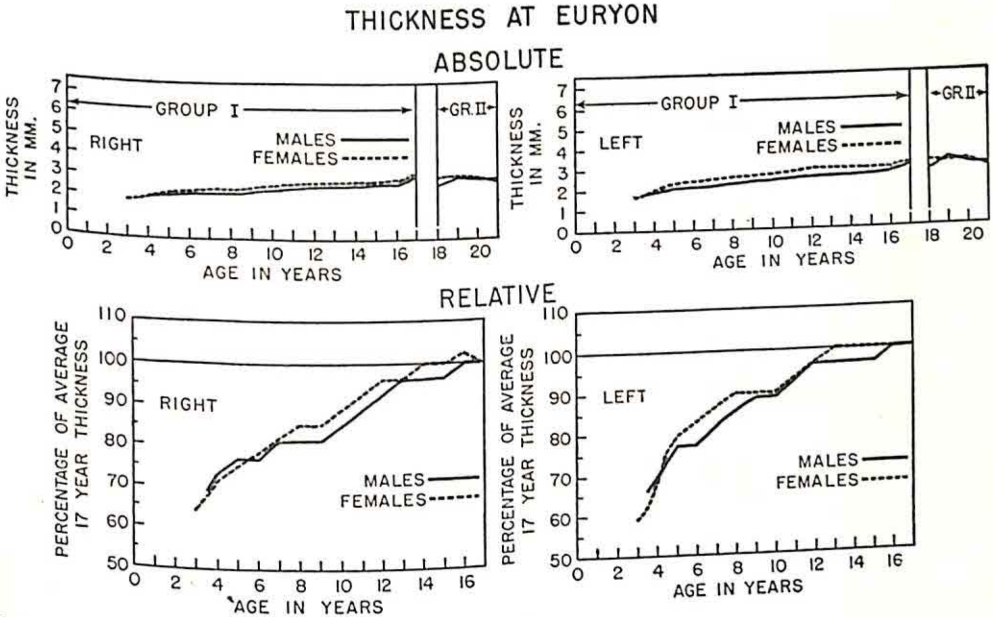


Fig. 3. Graphs Showing Absolute and Relative Skull Thickness at Right and Left Eurya.

In those graphs which show the average thickness as a percentage of the average 17-year old thickness, it will be seen that the female group is more advanced than the male group after the age of 6 years on the right and after the age of 4 years on the left.

SUMMARY

1. Cranial thickness has been measured on radiographs of white Americans taken under standardized conditions using the Bolton-Broadbent cephalometer.

2. Serial radiographs of 32 children between the ages of three months and 17 years were examined and the study was prolonged to 21 years by the inclusion of radiographs of different individuals.

3. The average cranial thickness of the males exceeds that of the females at all points where measurements were made except at euryon.

There is no significant difference in cranial thickness at euryon on the right and left sides.

4. At all points where measurements were made the rate of increase in thickness was reduced after about age 5 years but there was still a slight increase until 17 years. The only exceptions were in the female group where no increase was recorded at nasion after 15 years and at euryon after 12 years.

5. Females reach a greater percentage of the 17-year average thickness at any age than the males. Only at vertex after age 4 years do the males exceed the females in this regard.

6. After about age 6 years the frontal sinus resorbs the cranium in the plane of measurement at nasion and so a separate measurement of "bone thickness only" has been recorded at this point. "Bone thickness only" gradually declines between 3 to 14 years and then remains fairly constant at a figure approximately equal to the thickness at 6 months.

I wish to acknowledge my indebtedness to Dr. Normand L. Hoerr and to Dr. B. Holly Broadbent who, besides making these records available, helped me in innumerable other ways.

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GROWTH AND DEVELOPMENT OF THE CHIMPANZEE; A LONGITUDINAL AND COMPARATIVE STUDY *

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INTRODUCTION

HUMAN growth and development have been investigated by anthropologists for some time, but, by comparison, little is known concerning the details of these processes in any of the anthropoid apes. It was to fill this gap that some 12 years ago Dr. Henry W. Nissen of the Yerkes Laboratories of Primate Biology inaugurated a program for the longitudinal study of chimpanzee (Nissen, '42). During its first 7 years the program was assisted by generous grants from the Samuel S. Fels Fund. One aspect of this project was the collection of the physical growth data dealt with here. I wish to express my indebtedness to Dr. Nissen for the opportunity to analyze these data and for his continued interest, advice, and assistance during the progress of the work.

The present investigation centers around two main problems: first, resemblances and differences in growth (increase in size) and development (change in form) between chimpanzee and man; second, the determination of a methodology which will present these resemblances and differences in a simple and useful form. Both questions have importance not only for the general study of animal growth but also for the fuller understanding of the relative position of man and chimpanzee within the primates.

Previous studies have contributed to the over-all picture of non-human primate growth, but in general they have suffered from a number of difficulties. Most of the data have been cross-sectional and were obtained from animals of unknown age. Even where the same animal was measured repeatedly, its age has usually been determined by morphological comparisons with animals also of unknown age. This circular process, although admittedly unsatisfactory, was unavoidable. Of even more importance, usually little or nothing was known about the conditions under which the animal lived prior to examination. The present longitudinal study of laboratory-born and reared chimpanzees avoids all such handicaps.

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* Revision of a thesis submitted for the degree of Doctor of Philosophy in Anthropology, University of Chicago, 1953.

A number of papers have come from these Laboratories dealing with various aspects of chimpanzee growth. Whenever pertinent, their data have been incorporated in the present paper. Bingham ('29) dealt with linear measurements, but since his subjects were all of estimated birth date, these data were not used. Jacobsen, et al. ('32) described the weight growth of one animal for the first year. Spence and Yerkes ('37) and Grether and Yerkes ('40) have reported on normal weight growth. There were 5 papers (Nissen and Yerkes '43, Nissen and Riesen '45, '49a, '49b and Clark '45) which dealt with various aspects of the general problem of chimpanzee growth, but as no new data are available, their problems are not reconsidered.

Other chimpanzee growth studies are those of Noback ('31) and Budd, et al. ('43), who give longitudinal data for a comparatively short age range. In 1940, Schultz published his monograph on "Growth and Development of the Chimpanzee" in which he presented not only the results of his own extensive research, but also brought together the published data which were then available. The present paper, based on more adequate data, is, in a sense, an extension of this earlier study.

DATA

All original data are longitudinal in nature and were obtained from animals born and reared at the Yerkes Laboratories of Primate Biology. The basic data are from 16 animals, 9 males and 7 females, who are referred to as the Normative Group. These animals were separated from their mothers immediately after birth and raised in the Laboratories' nursery where they could be continuously observed and studied. Although these animals were born successively over a period of 3½ years, the conditions under which they lived were uniform in most essentials. Environmentally this is a very homogeneous group.

According to the original plan of the study, the Normative Group was measured monthly for the first year, quarterly for the next two years, and then yearly. In general this schedule has been kept, but from time to time circumstances forced some variation. Sometimes it was impossible to measure a given animal at all, and occasionally only certain measurements were possible. All changes in this schedule cannot be given in detail, but the brief summary in table 1 gives the animals' names and identification numbers (odd male, even female) and the age-range during which measurements were taken. The final column shows the number of sets of measurements, not all complete. For one animal, Jent, the study began at two months instead of at birth as for all the others. Spratt died at one year, but as his death was sudden, he was considered normal and was, therefore, included. There are 366 sets of measurements covering the age range from birth to 12 years.

TABLE 1

Chimpanzees of the Normative Group and the data available for each animal

ANIMAL'S		AGE (MOS.) AT FIRST AND LAST MEASUREMENT	NUMBER OF SETS OF MEASUREMENTS
NUMBER	NAME		
55	Ken	Birth–144	30
57	Art	Birth–144	25
59	Alf	Birth–132	30
61	Bard	Birth–144	31
65	Scarf	Birth–120	27
67	Jed	Birth–132	22
71	Jent	2–120	15
73	Spratt	Birth– 12	6
79	Web	Birth–108	16
90	Jenny	Birth–144	31
94	Jojo	Birth–144	30
98	Banka	Birth–132	27
100	Flora	Birth–132	25
102	Fanny	Birth–120	19
104	Falla	Birth–120	16
106	Karla	Birth– 96	16
Total	16	Birth–144	366

The complete set of measurements used in the present study includes the following: weight, trunk height, hip breadth, thigh length, leg length, knee height, foot length, upper arm length, forearm length, hand length, head length, head breadth, upper face height, and biorbital breadth. Paired measurements are for the left side only.

The measuring technique was essentially that described by Schultz ('29). Those measurements which differ from his description are:

Upper arm length: instead of acromion, the point used was the most superior point on the head of the humerus when the arm was extended across the chest. The values so obtained are slightly less than Schultz' and closer to those taken directly on the bone. The difference is not great.

Forearm length: this is ulna rather than radius length. The measurement was taken from the most distal point on the ulnar styloid process to the most proximal point on the olecranon process.

Biocular breadth: distance between the two points on the orbital margins opposite the ectocanthi.

Upper face height: naison was taken as the mid-line point between the entocanthi; the measurement was taken to the most inferior point on the upper medial incisors.

All data were recorded and are presented here in the metric system, the weights in tenths of a kilogram and the linear measurements in tenths of a centimeter.

The collection of weight data has been a cooperative task of many members of the Laboratories since their foundation. As the same method of weighing has been used consistently and as the beam scales have been checked periodically, there is no question of comparability of earlier and later data. Most of the linear measurements were taken by H. W. Nissen and A. H. Riesen, the remainder by the author. The same instruments were used throughout, and the individuals concerned have repeatedly checked themselves so that their technique would be consistent and comparable.

After infancy, when the animals were large enough to resist, the linear measurements were taken with the animal under barbiturate anesthesia, thus eliminating errors caused by the animal's struggles and muscle tension.

Supplementary data from animals not in the Normative Group have been used in the determination of the duration of the subdivisions of the total growth period and for the curves of normal weight growth. In each case the inclusion of such data is indicated.

For human comparisons, the data published by Simmons ('44) on the Brush Foundation children (Cleveland, Ohio) were used. This series was selected because the data are longitudinal, extending from three months to 17 years, and the children came from homes where above average nutrition and medical care were available. In these respects the human and chimpanzee subjects are probably reasonably comparable.

In the Brush study, forearm length is length of radius; there is no measure of biorbital breadth, upper face height, or foot length; also, there is no direct measurement of either trunk height or thigh length. Trunk height curves were obtained by subtracting the mean for symphysial height from the mean for suprasternale height. Thigh length was obtained by subtracting the knee height mean from the symphysial height mean.

SUBDIVISIONS OF THE TOTAL GROWTH PERIOD

The age span of growth may be divided into periods on the basis of certain events which occur in the life of each individual. The most convenient ones to use are birth, completion of the deciduous dentition, puberty, and completion of linear growth. Postnatally these events delimit infancy, childhood, and adolescence.

The duration of each of these periods in months is given in table 2a while in table 2b the duration is expressed as a percentage of the total growth period, conception to completion of growth. In the construction of these tables all the available data in these Laboratories have been used to determine the chimpanzee values.

TABLE 2A

Duration (in months) of the subdivisions of the total growth period

GROUP	SUBDIVISIONS OF THE TOTAL GROWTH PERIOD				TOTAL
	PRENATAL	INFANCY	CHILDHOOD	ADOLESCENCE	
Chimpanzee					
Male	7.6	12.2[a]	(102.4)	20.4	142.6
Female	7.6	11.3[a]	93.7	19.0	131.6
Human					
Male	8.8[b]	27.6[c]	(161.2)	39.2[e]	236.8
Female	8.8[b]	28.4[c]	136.4 [d]	39.2[e]	212.8

[a] Nissen and Riesen '45 [b] Taback '51 [c] Robinow, et al. '42
[d] Ellis '50 [e] Flory '36

TABLE 2B

Duration of the subdivisions expressed as a percentage of the total growth period

GROUP	SUBDIVISIONS OF THE TOTAL GROWTH PERIOD				TOTAL
	PRENATAL	INFANCY	CHILDHOOD	ADOLESCENCE	
Chimpanzee					
Male	5.3	8.6	(71.8)	14.3	100.0
Female	5.8	8.6	71.2	14.4	100.0
Human					
Male	3.7	11.6	(68.1)	16.6	100.0
Female	4.1	13.4	64.1	18.4	100.0

The length of the chimpanzee gestation period has been previously discussed by Yerkes and Elder ('37), Nissen and Yerkes ('43), and to some extent by Gavan ('52a). A much larger sample is now available; the length of the gestation period in days is given in the following tabulation:

	MALE	FEMALE	TOTAL
Number of cases	44	41	85
Range (days)	196–248	203–260	196–260
Average duration (days)	224.9	229.6	227.2
Standard deviation	11.8	11.4	11.8

Since the difference between the male and female averages is not significant, the sexes were combined. This gives an average gestation period (conception to birth) of about 32½ weeks, or about 5 weeks less than the average human gestation period (Taback, '51). Length of human gestation is usually counted from the last menstruation instead of from the day of conception; to obtain conception age, 14 days were subtracted from Taback's average. This yields a human gestation period of 263.7 days.

The age for the completion of the deciduous dentition is taken from Nissen and Riesen ('45) and is based on the 16 animals of the Normative Group. A tooth was considered to have erupted when it projected 1 mm through the gum. According to these authors, the chimpanzee's deciduous dentition is complete, on the average, at 366 days for males and 339 days for females; comparable figures for human children are 828 and 852 days for boys and girls respectively (Robinow, et al. '42).

Puberty is not a point in time but includes a temporally extended series of events. For simplicity, the time of the first menstruation in females is used to indicate the onset of puberty. All animals used in determining the average age of puberty were not born in these Laboratories, but those not born here came at an estimated age of less than 48 months. Ages at menarche are as follows:

	FEMALES OF ESTIMATED AGE	LABORATORY BORN FEMALES	TOTAL
Number of cases	7	14	21
Range (months)	96–129	84–122	84–129
Average age (months)	105.1	104.9	105.0
Standard deviation	12.5	12.9	12.5

The difference between the averages is not statistically significant so the two series were combined. This chimpanzee average of 8.8 years is 4.9 years less than that given by Ellis ('50) for 470 English nurses. However, the human range, 9.5 to 18.5 years, shows considerable overlap with the chimpanzee range.

For purposes of the present study, the end of the growth period was taken as that time when the epiphyses of the long bones in the shoulder, elbow, hip, and knee have completed at least one-half of the union with their diaphyses. (A set of roentgenograms was taken each time the animal was measured.) There are 7 animals whose age at reaching this criterion is known, 4 males and three females. The average for males was 135 months, range from 132 to 144 months; the female average was 124 months, range from 120 to 132 months. These results approximate the value of 11 years given by Schultz ('40) and that of 11 to 12 years given by Grether and Yerkes ('40) for age at completion of growth.

The female chimpanzee completes her growth about a year ahead of the male. Flory ('36) has shown that the skeletal development of girls becomes progressively more advanced over that of boys as age increases; by assuming that this is true in the chimpanzee as well, the average age of male chimpanzees at puberty was placed 0.8 years after the female. As this is a calculated value, the age at puberty in males given in Table 2a has been placed in parenthesis.

The values for human children have been taken from a number of sources as indicated in the table. The assumption that boys reach puberty two years after girls is based on the relation between puberty and age of maximum growth which, as Shuttleworth ('39) has shown, occurs two years earlier in girls than in boys. This value has also been placed in parenthesis.

Taking Table 2a as a whole, it can be seen that there are both sex and species differences in the absolute length of the parts of the growth period. The chimpanzee completes each part in an absolutely shorter time than do human children. The chimpanzee female completes each part sooner than does the male with the exception of the pre-natal period. The same is apparently not true for human children where girls require more time to complete infancy than boys.

When the length of each subdivision is expressed as a percentage of the total growth period (table 2b), the differences between the male and female chimpanzees practically disappear. The timing of events within the total growth period is relatively the same for both sexes. The same may be true for the human data, although girls apparently require relatively more time to complete gestation, infancy, and adolescence than do boys. Perhaps some of these differences are due to the diverse origin of the data.

The species difference does not conform exactly with that given by Schultz ('40). He states that in chimpanzee the postnatal growth period is 15.7 times longer than the prenatal, while in man it is 27 times longer. The data of table 2a gives values of about 17.0 for chimpanzee and 24.5 for man. Schultz used the length of chimpanzee gestation period as 238 days; an average given by Yerkes and Elder ('37) for 17 births. He also measures the length of the growth period by the eruption of the third molars; a procedure which lengthens the postnatal period. (A paper on the age of eruption of the permanent dentition in chimpanzee is now in preparation by H. W. Nissen and A. H. Riesen.) Even considering the slight differences in the criteria of adulthood, it seems unlikely that the species differences in the relative duration of these subdivisions is significant. Humans have an absolutely longer total growth period, but the relative timing of events during growth is roughly the same in both species.

GROWTH: WEIGHT

Birth weight has been the subject of a previous publication, (Gavan, '52a). There it was shown that the average birth weight for 42 animals was 1.80 kg, with no significant sex difference. Using the same animals, birth weight expressed as a percent of mother's weight at time of conception averages 4.25% with a range from 2.29 to 5.80%. Schultz ('40) reports 4.00% for chimpanzee and 5.50% for man. Although the present data confirm his findings for the average chimpanzee, it is of interest that the chimpanzee range overlaps the human average.

According to Schultz ('40), the average, adult female chimpanzee weighs 40 kg and the male 45 kg; Grether and Yerkes ('40) give the same value for females but 50 kg for males. However, adulthood is not a point but rather a period of time, and at least in primates it is the longest part of the life span. In these Laboratories there are females who at 32 years are still capable of having children; therefore, chimpanzee adulthood lasts at least two-thirds of their total life span. During this relatively long period, weight changes can be expected. For American, white women maximum weight is not reached until about age 52 (O'Brien and Shelton, '41, fig. 9). In chimpanzee as well, weight continues to increase after adulthood is reached and declines after attaining a maximum value. It was felt that this maximum value would be more representative of adult weight than an average determined at some arbitrary time level. To obtain an estimate of maximum weight, it was assumed that by 150 months (12.5 years) any chimpanzee would be an adult; the maximum weight achieved by each animal after this age was taken as its adult weight. No animal was used who had been in an experiment which could affect subsequent weight nor was any female used during pregnancy or periods of child raising. These restrictions left 9 males and 25 females, most of whom were wild born animals, whose records were examined to a maximum age of 320 months for males and 385 months for females. The averages of the maximum weights are 53.4 kg and 49.2 kg for males and females respectively; the ranges, 40.8–64.1 and 37.7–84.4, show almost no sex difference. Even if the heaviest female be considered abnormally obese and eliminated, the female maximum is reduced only to 63.6 and the average to 47.7 kg. The adult sex difference is an average difference only with considerable individual variation.

These average weights cannot be considered as the maximum possible average adult weight. Some of the animals had just reached 150 months while others were not much older. That there is a real trend towards increased weight during adulthood, at least in males, is shown by the correlation between observed maximum weight and age at which this weight is achieved, r = .85, significant at the 1% level of confidence. The female correlation, r = .33, is not significant even at the 5% level, but female weights are complicated by the after-effects of pregnancies. Of 85 births resulting in viable offspring, 32 were to mothers between 152 and 208 months of age while 28 were to mothers 214 to 337 months of age. If it had been possible to use females who had never been pregnant, the maximum weight would undoubtedly have been attained prior to the average age of 212.4 months actually found. The males attained their maximum weight at 166.4 months.

For weight growth between birth and 144 months, only animals born in these Laboratories were used. Animals who had participated in what might have been a deleterious experiment were eliminated. No infant weight was used until at least 6 months after separation from the mother unless such separation occurred at birth. No female weights during periods of pregnancy or child raising were used; there were 25 infants born to females between 100 and 144 months of age. In all, there were 37 males and 29 females used in the construction of the weight curves. Of these, 5 males and 10 females were used in the previous calculation of adult weight.

The weight range by chronological age is plotted in figure 1. The gradual increase in variability and the sex overlap in the range are shown. At 12 months the males range from 4 to 8 kg and the females from 6 to 8 kg; at 36 months these ranges have becomes 10 to 15 and 12 to 16 kg, and by 108 months they are 27 to 44 and 28 to 47 kg. This great overlap in the range emphasizes that the trends shown in figure 2 are those of the central tendency only.

The range shows a consistent increase until at least 120 months. By 144 months, the female distribution seems to be leveling off, but the male distribution is apparently still increasing.

For sex and species comparisons, the average chimpanzee and human weights have been plotted against chronological age in figure 2. The chimpanzee curves have been extended by eye to the previously determined adult maximum weight; the human data have also been extended to a plateau by a smooth curve. These extensions are indicated by dotted lines. Until 30 months, there is no sex difference in the chimpanzee curves. Subsequently until 120 months the females are, on the average, the heavier. Then the males go ahead to 46.5 kg while the females attain 41.8 kg by 12 years of age.

This picture is somewhat different from that previously given by Grether and Yerkes ('40) who found no sex difference until 7 years when the males become the heavier and remain so. Some of these differences may be due to the fact that they used both wild and laboratory born animals whereas the present study is restricted to the latter group. It may be that early environmental conditions, even though of short

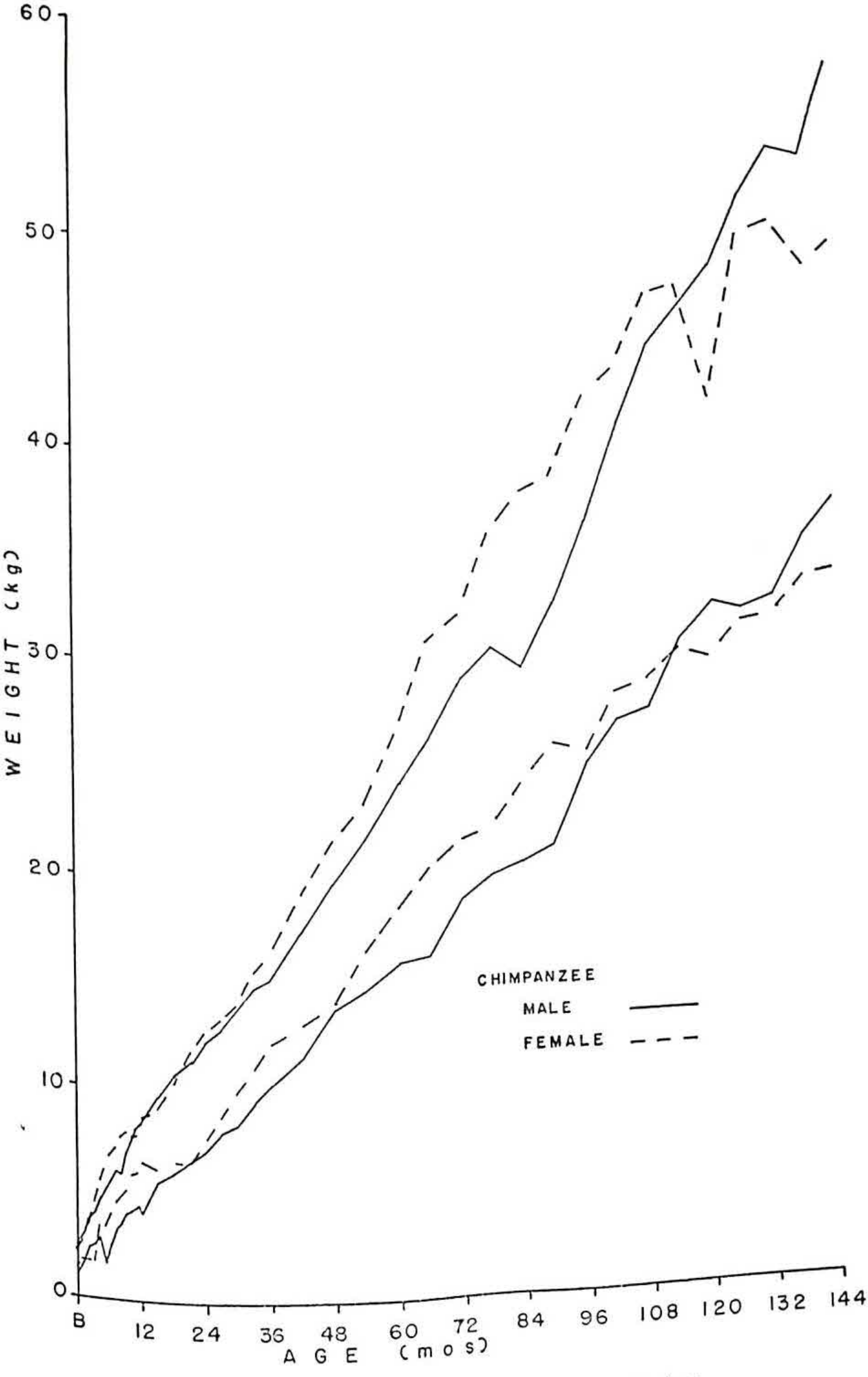


FIG. 1. WEIGHT RANGE BY CHRONOLOGICAL AGE.

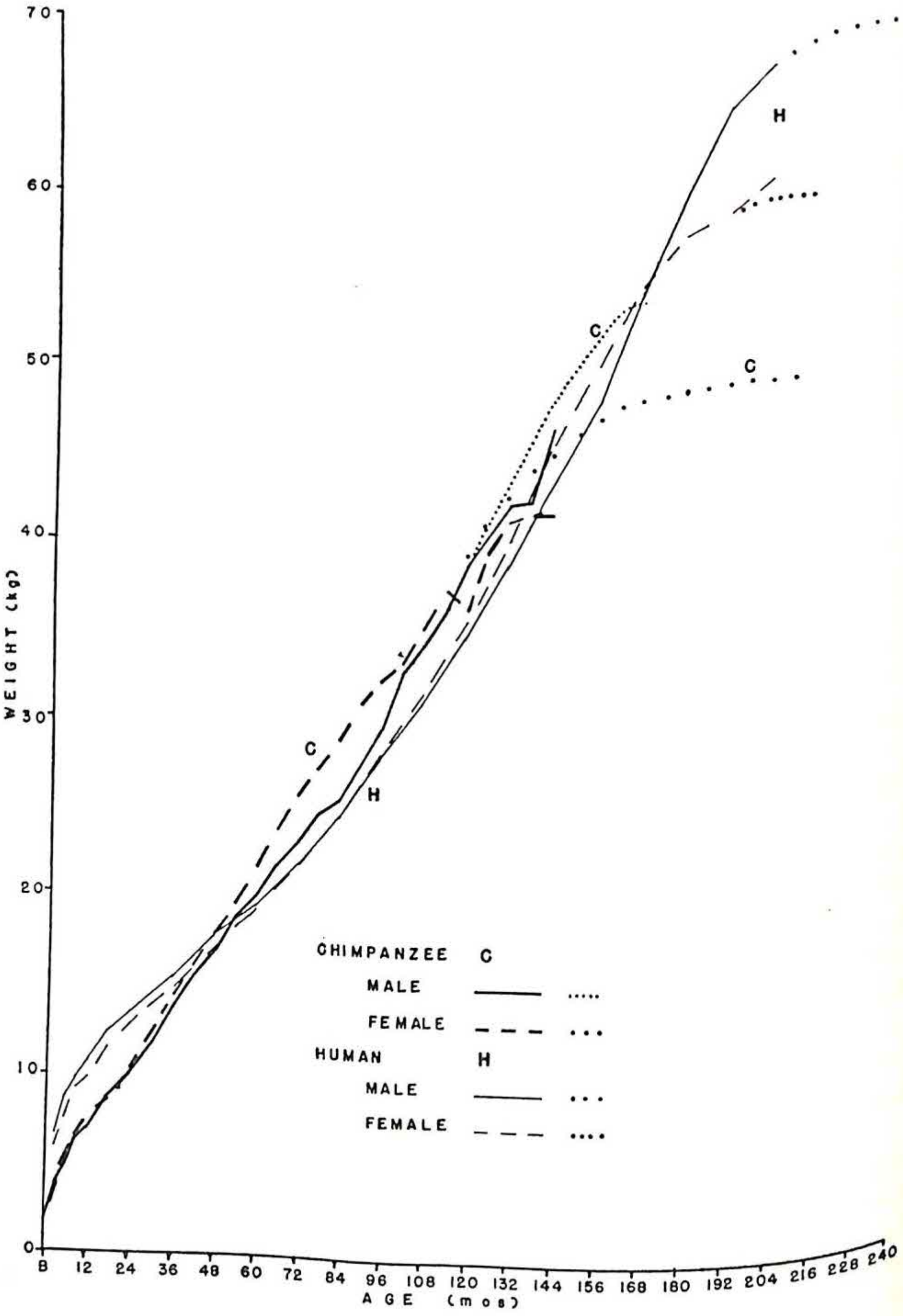


FIG. 2. AVERAGE WEIGHT BY CHRONOLOGICAL AGE.

duration, have a permanent effect upon subsequent growth. This appears to be the more likely reason, but it is possible that some unavoidable errors were made in estimating age, errors which could alter the entire growth curve.

The species comparison, figure 2, shows two points of interest. Throughout the human growth curve there is a well marked sex difference, except at the two points where the curves cross. Boys are initially and finally heavier than girls, but during the pubertal period girls surpass them. This double crossing of the curves does not occur in chimpanzee.

Secondly, although the human child is heavier at birth and during adulthood, the chimpanzee is heavier for a part of the intervening period. Male chimpanzees are heavier than boys of the same chronological age from about 4½ to 14 years; female chimpanzees are heavier than girls from 3½ until 12 years.

The rate of weight growth has been studied by means of average annual increments, figure 3. The absolute amount of average gain per year is plotted against chronological age; the dotted lines give the increments as computed from the extended curves in figure 2. In general all 4 curves are of the form found in primate growth. There is a rapid decline after birth, a gradual increase culminating about puberty, and a final decline to zero as maximum adult weight is attained.

Until about 7 years females, chimpanzee and human, are growing faster than males of the same species; during this same time chimpanzees are growing faster than human children. There follows a period of about three years when male chimanzees are growing considerably faster than the other three groups who follow pretty much the same course. At approximately 10 years, just before for the female and just after for the male, the chimpanzee curves begin to decline. The male curve reaches zero before the female because of the latter's extended period of weight growth as discussed previously. At this same time, 10 years, the human curves are still rising until human children are finally growing absolutely faster than chimpanzees.

All 4 curves show an age of maximum growth. In the human curves, these peaks are reached before puberty, indicated by the lines at the top of the graph, but the chimpanzee peaks come just after puberty. This raises the question of what, if any, causal relation there may be between the age of maximum growth and puberty. In figure 4, the annual increments are plotted against the percent of maximum weight attained at the beginning of the year. In all 4 curves, the maximum

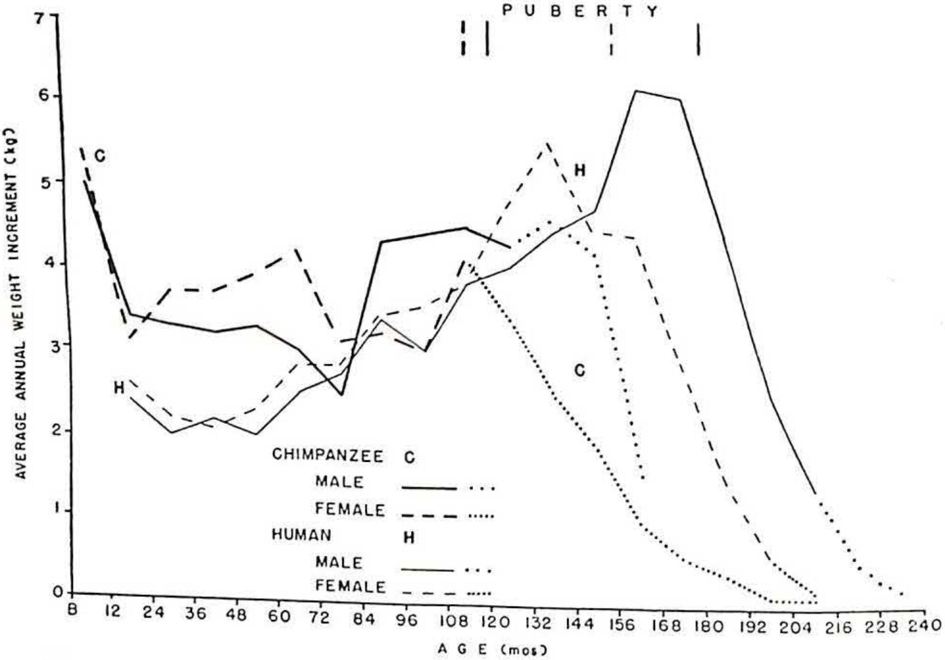


FIG. 3. AVERAGE ANNUAL WEIGHT INCREMENTS BY CHRONOLOGICAL AGE.

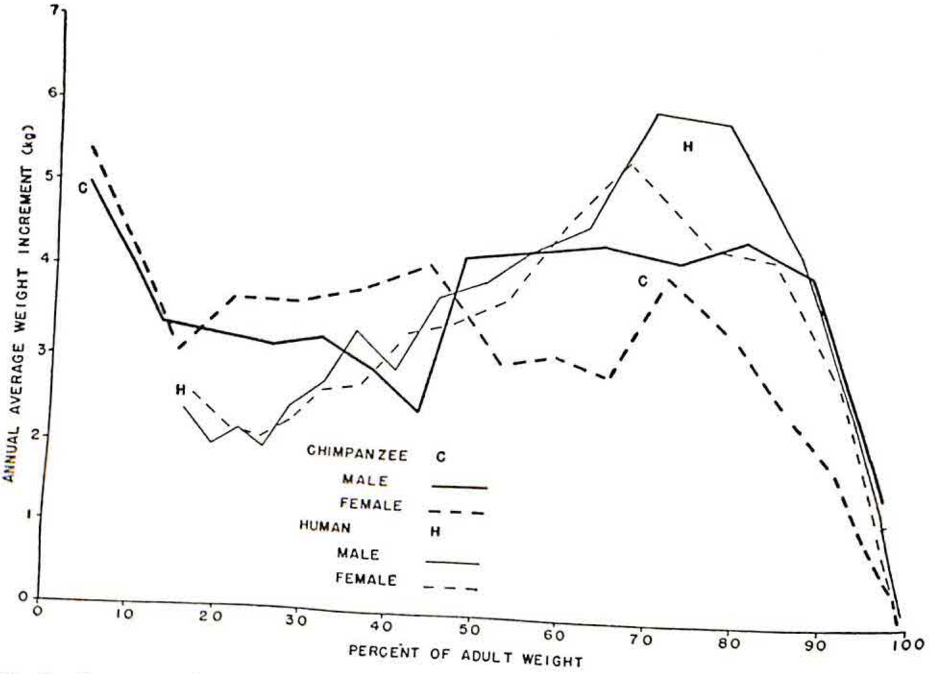


FIG. 4. AVERAGE ANNUAL WEIGHT INCREMENTS PLOTTED AGAINST THE PERCENT OF ADULT WEIGHT ATTAINED AT THE BEGINNING OF THE INCREMENT.

increment occurs at approximately 70% of mature size. This point is reached before puberty by human children but after puberty by chimpanzees. Although the problem is not solved, this relation indicates an alternative explanation for the occurrence of the age of maximum growth. It may simply mark the approach of adult size which in primates is achieved shortly after puberty.

GROWTH: TRUNK HEIGHT

In human studies, stature is usually used as the linear measure of body size, but the low correlation between the segments of stature found by O'Brien and Shelton ('41) and the comments by Howells ('51) would indicate that the value of stature for such purposes is limited. In non-human primates, stature is almost meaningless; the measure of linear body size is really trunk height, long used by Schultz as a base for computing indices. Unfortunately, Schultz rarely gives the absolute values for trunk height so that growth in this important linear dimension is virtually unknown.

Average trunk height curves for chimpanzees (fig. 5) have initially a high rate of growth which gradually decelerates to a plateau by 12 years. During the first year, the average male chimpanzee increases 62% and the female 67.1% over their average birth measurement. Thereafter, the yearly percent increase gradually declines. (The female increase between 11 and 12 years is due perhaps to the fact that only two animals were measured at the later age. This is true for some subsequent curves as well.)

The Brush curves do not begin until 18 months when the human child is only slightly longer than chimpanzees his own age. Taylor (in Krogman, '41, p. 77) gives, for white new-born children, an average trunk height of 22.4 cm with a range for boys of 19.0–26.0 and for girls 18.9–25.8. These minimum values exceed the chimpanzee maximum birth values and stress the small absolute size of the newborn chimpanzee.

By two years of age all 4 groups; male and female, chimpanzee and human; have essentially the same trunk height. At this time the male chimpanzee has increased his birth length 87.3%, and the female 94%. Boys have increased only 28.6%, and girls 27.7%. At birth the chimpanzee trunk height is only 67% of human trunk height, but growth is so much faster in chimpanzees that this difference disappears by two years of age.

The chimpanzee continues this more rapid growth so that for the next 10 years (from two until 12) the male is longer than boys of the same age. During this same period the female chimpanzee is longer than the male and remains longer than human girls until at least 13 years of age.

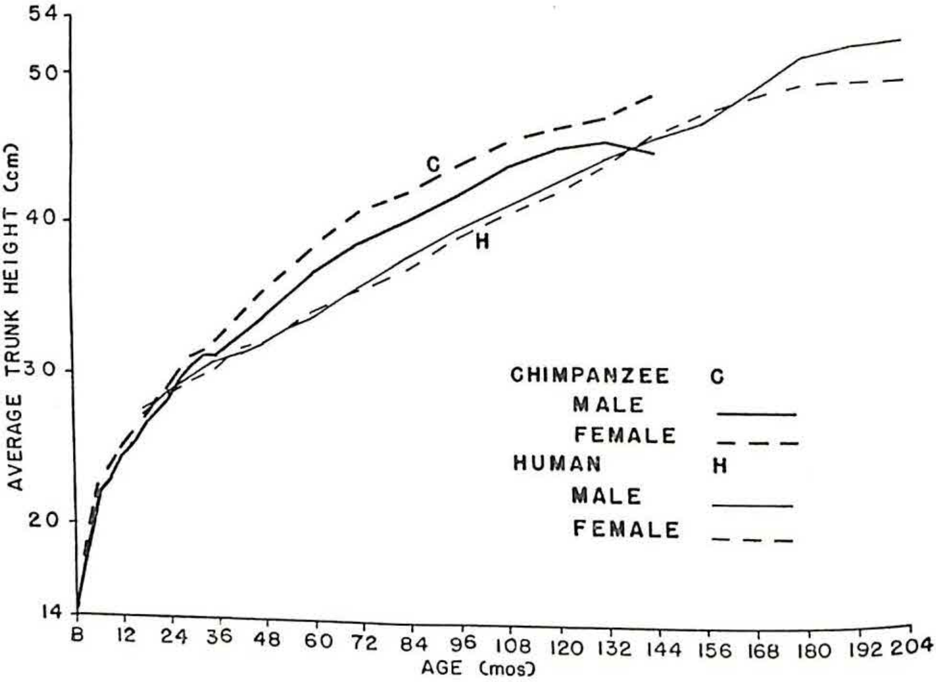


FIG. 5. AVERAGE TRUNK HEIGHT BY CHRONOLOGICAL AGE.

This size superiority of the chimpanzee actually has two causes. The male chimpanzee reaches his final size by 12 years of age whereas boys do not reach theirs until at least 18 (at 17, the final age in the Brush study, boys are still increasing). A similar situation exists for females so that the growth period for chimpanzee trunk height is about 60% of the human growth period. Secondly, during the postnatal period, the male chimpanzee increases his trunk height 30 cm and the female 32 cm. The same increase for human children is 29.8 cm and 27.0 cm. Chimpanzees grow an absolutely greater amount in trunk height in a shorter period of time than do human children.

It is apparent, therefore, that there are at least two variables in these growth curves; the size reached at adulthood and the length of time required to reach that size. To determine what other differences there might be between the curves, figure 6 was constructed. There, age is expressed as a percent of the total growth period (see table 2a), and trunk height is expressed as a percent of adult size. The curves now show remarkable similarity indicating that most of the differences in figure 5 are due to these two variables, final size and duration of growth time.

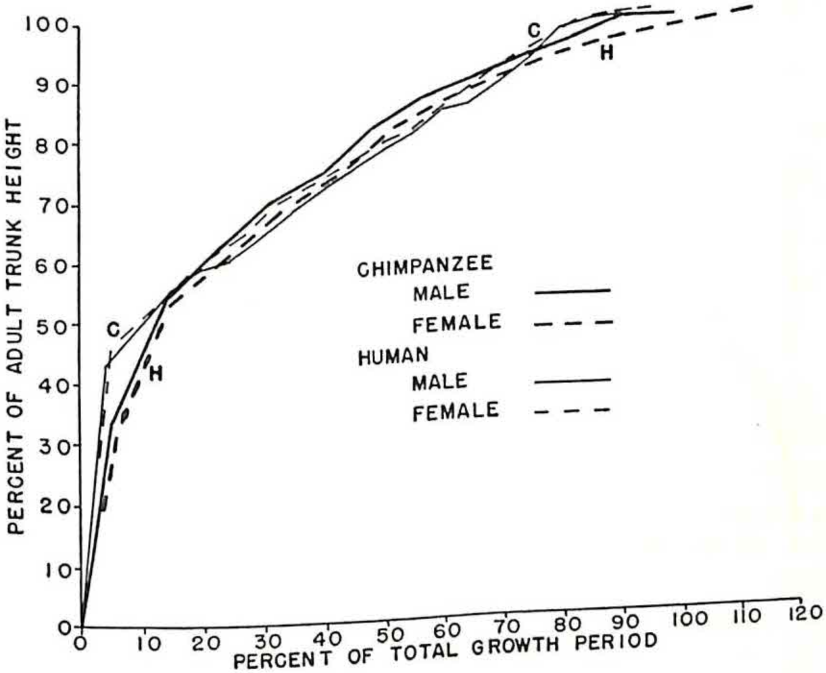


FIG. 6. PERCENT OF ADULT TRUNK HEIGHT PLOTTED AGAINST PERCENT OF THE TOTAL GROWTH PERIOD.

There are still some differences which may be significant. Prenatally the human curves show a larger increase than the chimpanzee's. At birth (4% of the total growth period) the human child has about 44% of his final trunk height; whereas, the chimpanzee at birth (5% of the total growth period) has only 32% of his final trunk height. Even after allowing for the difference in length of the gestation period, humans attain relatively more of their adult trunk height prenatally than do chimpanzees. But this relative superiority is not maintained; for a period of time, greater for the male than for the female, the chimpanzee is relatively longer than the human child. After completing about 70%of their total growth period human children show a spurt, which does not occur in chimpanzee curves, and reach their maximum size relatively earlier than the chimpanzee.

The sex comparison shows another species difference. In the chimpanzee curve the male is always relatively larger than the female, but the human girl is usually relatively larger than the boy (there are two exceptions, at 14% and at 80% of the total growth period). Whether these differences would be accentuated or reduced by more adequate data is impossible to say. The final size for human boys has had to be estimated by extrapolation of the Brush curves, and possible errors in the relative age scale have already been discussed. Even with these reservations, it is apparent that most of the species differences in figure 5 can be eliminated by equating the age and size scales as in figure 6. Human beings have a longer growth period and reach a larger final size, but the growth curves connecting these end points with conception are virtually the same in both species.

DEVELOPMENT: TRUNK HEIGHT—BODY WEIGHT

Change in form during growth, i. e. development, is usually studied by means of an index or ratio in which one measure is expressed as a proportion of another. An increase in the index with age indicates that the numerator of the fraction is increasing faster than the denominator. Gross form changes may be expressed by any one of the many variations of the ponderal index in which weight is expressed in terms of some measure of linear size. In the present study the ponderal index has been calculated from the average values by dividing weight times 100 by trunk height. (These weights are for the Normative Group only.) As shown in table 3, weight increases faster than trunk height; whereas the indices are less than 45 at the beginning they are almost 100 for chimpanzees and well over 100 for human children by the end of the growth period.

Although all 4 groups show an increase, the curves are not parallel. At 18 months human children are relatively heavier than chimpanzees, human index over 40 and chimpanzee index under 35. At 48 months they are almost the same with only 2 index units separating the minimum from the maximum. Therefore, during the first 4 years chimpanzees increase their relative weight faster than human children. For the next 5 years, there is not much difference between the groups;

TABLE 3

The ponderal index (100 × weight/trunk height) for the Normative Group and for human children (Brush)

AGE	CHIMPANZEE		HUMAN	
	Male	Female	Male	Female
B	12.0	12.1	——	——
6	24.1	22.9	——	——
12	30.4	28.9	——	——
18	34.5	33.6	44.7	41.2
24	38.4	38.0	45.8	43.7
30	40.2	40.3	47.5	45.6
36	44.7	44.2	49.4	48.2
48	52.2	52.0	54.0	52.2
60	55.6	57.4	57.2	56.0
72	60.2	64.4	60.8	61.0
84	65.6	67.4	64.9	66.2
96	72.2	71.6	70.4	71.9
108	78.6	76.1	75.2	78.0
120	86.6	76.6	81.5	84.3
132	88.7	81.3	88.0	91.6
144	94.9	92.6	95.2	99.8
156	——	——	102.1	105.7
168	——	——	110.4	111.9
180	——	——	117.2	116.2
192	——	——	124.1	119.0
204	——	——	128.2	123.0

the greatest difference during this period is at 72 months where the range is from 60.2 for the male to 64.4 for the female chimpanzee. Subsequent to 9 years, female chimpanzees fall behind and become relatively the lightest; human girls become relatively the heaviest for a time and are finally surpassed by the boys. Beginning at 4 years there is a time of general similarity followed by large differences, but with each group changing its position in a rather bewildering fashion.

Previously (Gavan '52b), it was pointed out that there is an alternative way of looking at the height-weight relation, a way which in some respects is simpler and more instructive than the ponderal index. The method is (a) to use the cube root of weight instead of weight itself and (b) to make the comparison by means of a regression line. This method of comparison, cube root of average weight plotted against average trunk height is shown in figure 7, along with the regression equations and statistical measures of variability. (Statistical methods and symbols are those of Fisher, '46.) All regression equations and all indices have been calculated from the average values and not from the individual data.

Regression as a means of comparison has certain advantages over an index. In both methods, the data must be available in pairs, but in the index method these pairs are used one at a time. Chance fluctuations in the original data are augmented. In regression, all pairs are considered simultaneously, and the resulting equation shows the main trend of the data independent of minor variations. When dealing with small samples, as in the present study, this ability to identify the main trend is of major importance.

Regression also makes possible the interpolation of missing values. The chimpanzee and human children were not always measured either at the same age or at the same linear size. At such ages and sizes no comparison is possible with an index unless the investigator uses some subjective smoothing process. By considering the data as a whole, regression overcomes this difficulty. For the study of individuals rather than averages this possibility of interpolation is of considerable advantage as the subjects need not be studied at either the same or at regular intervals.

However, the use of regression also presents some difficulties; the principle one is the choice of which type of regression to use. A cursory examination of the literature would reveal any number of types ranging from simple, linear regression (Shepard, et al., '49) to simple, exponential regression (Huxley, '32) and on to the complex equations used by Count ('43). It would appear that the simpler forms have greater utility as the constants are easier to calculate and easier to interpret. These are advantages only if it can be shown that the simpler equation actually fits the data.

In figure 7 the linear equation $Y = \bar{y} + b\ (X - \bar{x})$ has been used. The fit of the equation can be judged by the coefficient of determination, equal to the squared coefficient of correlation. The coefficient of determination expresses the relative amount of variability in the dependent variable which is associated with the variability of the independent variable. Figure 7 shows that less than 1% of the original variability in the cube root of weight is not associated with the variability in trunk height. The assumption of linearity is these data is, therefore, justified.

The parameter b in the regression equation indicates the rate of increase in the dependent variable as compared to that of the independent variable. Because b is subject to sampling errors the significance of a difference between two b's must be determined by the t-test (Fisher, '46, p. 140). All regression equations were first calculated separately for each of the 4 groups; male and female, chimpanzee and human. For the cube root of weight compared to trunk height, the values of b were .071 and .074 for human boys and girls; male and female chimpanzees had values of .070 and .066. These sex differences are not significant for the human children but are significant for the chimpanzee. (A difference at the 5% level of confidence was considered significant. A summary of the levels of confidence for all significant differences is given in table 6.)

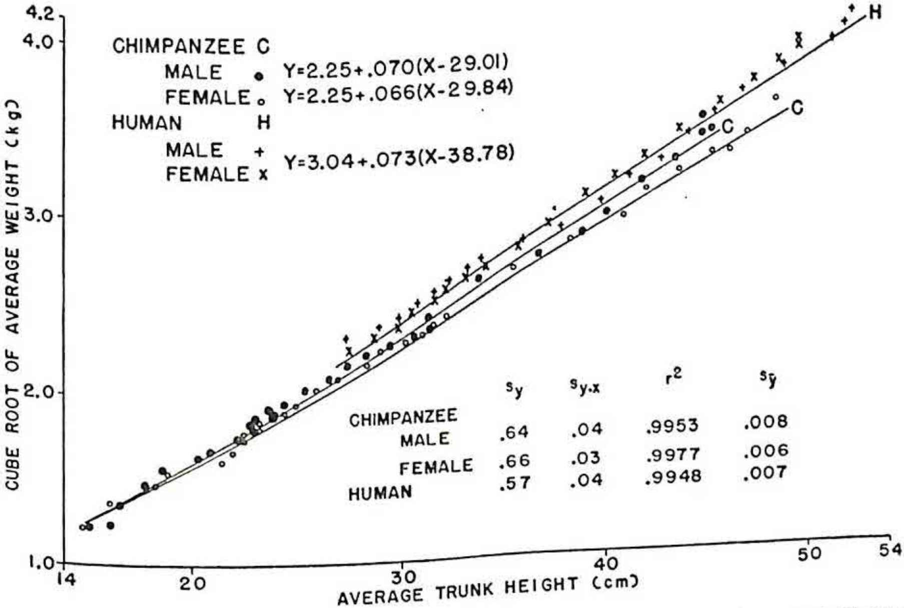


FIG. 7. REGRESSION OF CUBE ROOT OF AVERAGE WEIGHT ON AVERAGE TRUNK HEIGHT FOR THE NORMATIVE GROUP OF CHIMPANZEES AND HUMAN (BRUSH) CHILDREN.

The lack of a significant difference in b merely indicates that the two regression lines are parallel; to determine if there are two separate, parallel lines or if they superimpose on one another, the significance of the size difference must also be determined. This is done by calculating the standard error of the mean of the dependent variable when the independent variable is constant ($S_{\bar{y}}$ in the figures). The standard error of the difference is the square root of the sum of these two squared standard errors. The values for Y are calculated from the appropriate regression line using X equal to male $\bar{x}$. The difference is divided by the standard error of the difference and the quotient is equal to t. Its level of significance indicates whether or not there is a sex difference in size in the dependent variable which is independent of the differences in the independent variable.

In those cases where the difference between the *b's* is significant, the two regression lines are not parallel, and they must intersect. At the intersection there is no size difference, but as growth progresses from this point, a size difference will necessarily develop.

Regression thus makes possible the analysis of rate and size as two separate entities. It is possible to determine whether size differences in two dimensions are really independent of one another or are merely two measures of the same difference.

In the human data there is no significant difference in either rate or size. Therefore, in figure 7, one equation is given for the human sexes. As the difference in rate for the chimpanzee sexes is significant, two regression equations are necessary.

This type of analysis indicates that within each group the volumetric and linear measures of gross size maintain a constant relation and that in their development the groups hold a constant position with respect to one another. Regression shows a regularity during growth which is not apparent when the same data are analyzed by means of an index.

Because regression gives a simpler and more easily interpreted picture of development, the indices recommended by Schultz ('29) will not be used. In the linear regression equations, the denominator of his index will be used as the independent variable.

GROWTH AND DEVELOPMENT: HIP REGION

The bitrochanteric, hip breadth is the only available measure of chimpanzee growth in the pelvic region. Its average size according to chronological age is given in figure 8. The chimpanzee curve is similar to the previous one in that the initially rapid increase in size gradually decelerates. Unlike trunk height, hip breadth at 12 years is apparently still rising and perhaps indicates that growth in the pelvis continues longer than in other parts of the body. For the first two years males are slightly larger than females, but from 4 to 10 years the situation is reversed. The larger female size at 12 years may merely reflect an inadequate sample at this age.

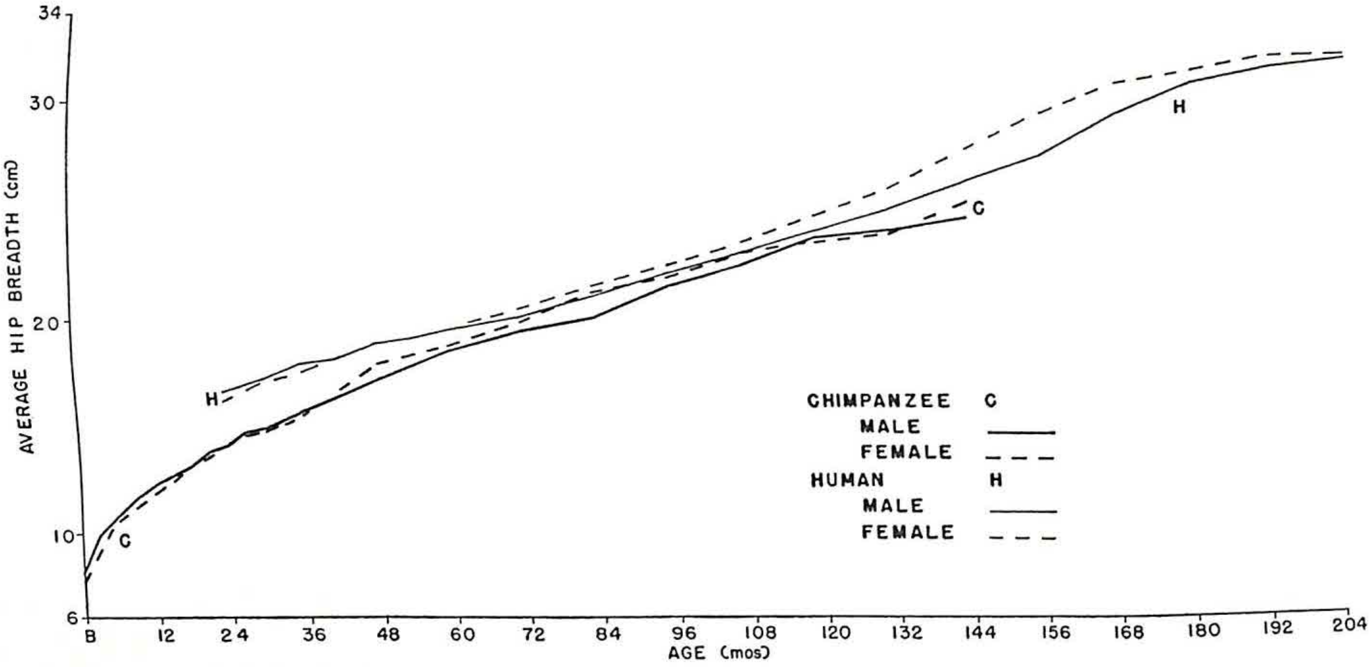


FIG. 8. AVERAGE HIP BREADTH BY CHRONOLOGICAL AGE.

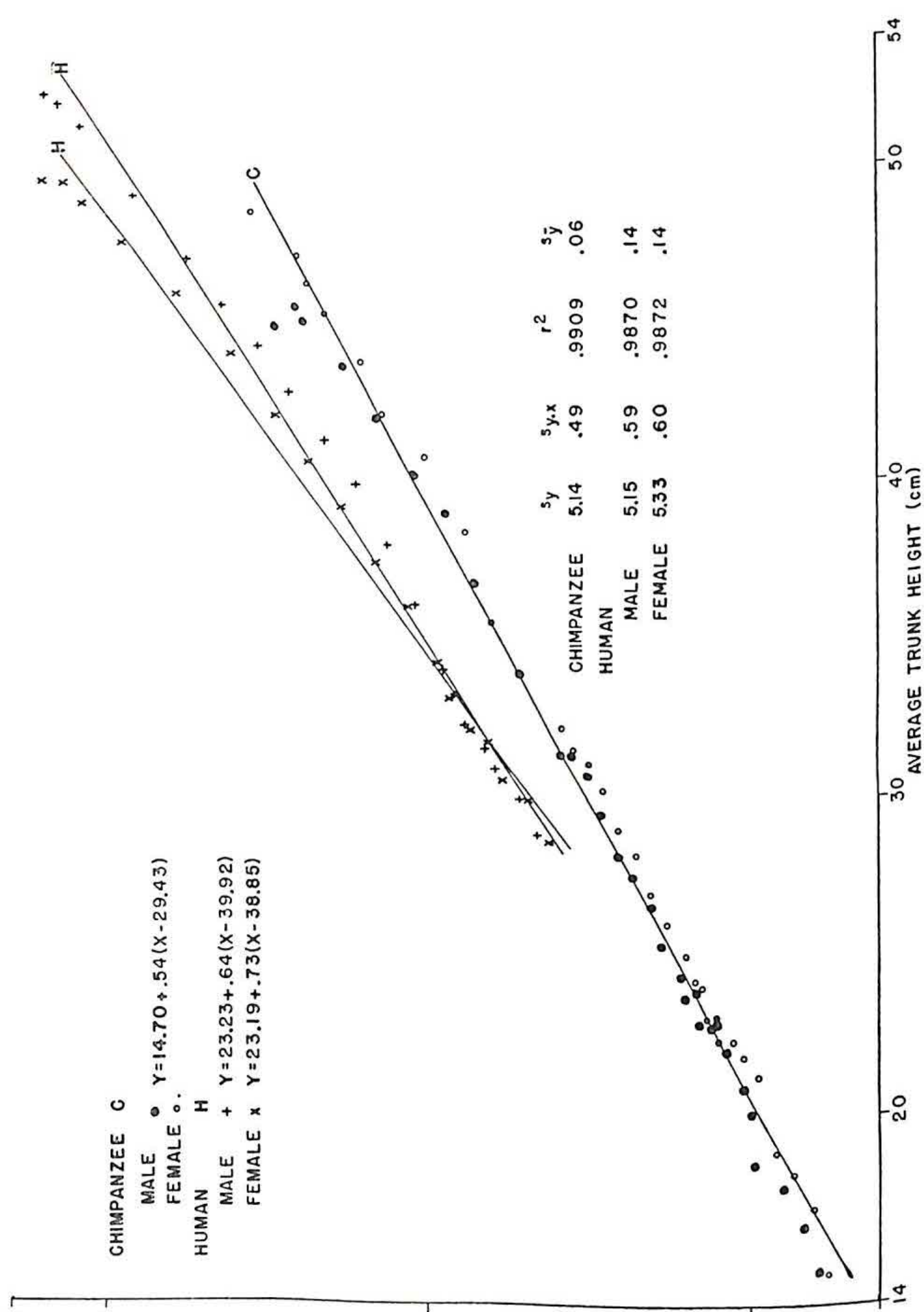


FIG. 9. Regression of Average Hip Breadth on Average Trunk Height.

The human curve is quite different. The initial rate slows down, but unlike the chimpanzee, there is a subsequent period of acceleration beginning about the seventh year and lasting until about the 14th year when growth again slows down.

In figure 9, hip breadth is plotted against trunk height; the linear regression equations and measures of variability are included. A comparison of the *b*'s shows that all differences are significant except that between male and female chimpanzees. When compared to trunk height, hip breadth grows significantly faster in girls than in boys, and faster in humans than in chimpanzees, but within the chimpanzee species there is no significant rate or size difference.

The values of r^2 indicate that most of the changes in hip breadth are associated with those in trunk height although to a lesser extent in humans than in chimpanzees. The distribution of the data with respect to the regression lines shows that the fit for humans is less satisfactory than for chimpanzees. In the latter species the points are scattered about the line, but in humans there are consistent trends away from it. The human data, both boys and girls, begin above their regression line, fall below it, and then return above it. This cannot be another sex difference as the data for each sex depart from their own line at the same size level and apparently to about the same degree. Therefore, in both species there are growth factors which are common to both trunk height and hip breadth, but in humans there are additional factors, common to both sexes and not found in the chimpanzee, which influence only one of the dimensions.

GROWTH : EXTREMITIES

Growth of the segments of the chimpanzee's upper extremity is shown graphically in figure 10. In all three segments there is an initially high rate of growth which gradually diminishes until growth ceases at about 11 years. From birth until almost two years, slightly earlier for hand length, male and female chimpanzees remain the same size, but from then until 10 years the female is larger. When growth is completed in both sexes the male is larger, indicating that the male increments are smaller but that they continue for a longer period of time. However, in the upper arm the difference in growth time is evidently not sufficient to make up for the slower rate, for even at 12 years the male is still smaller than the female.

Comparative human data (fig. 10) show that, as in trunk height, the

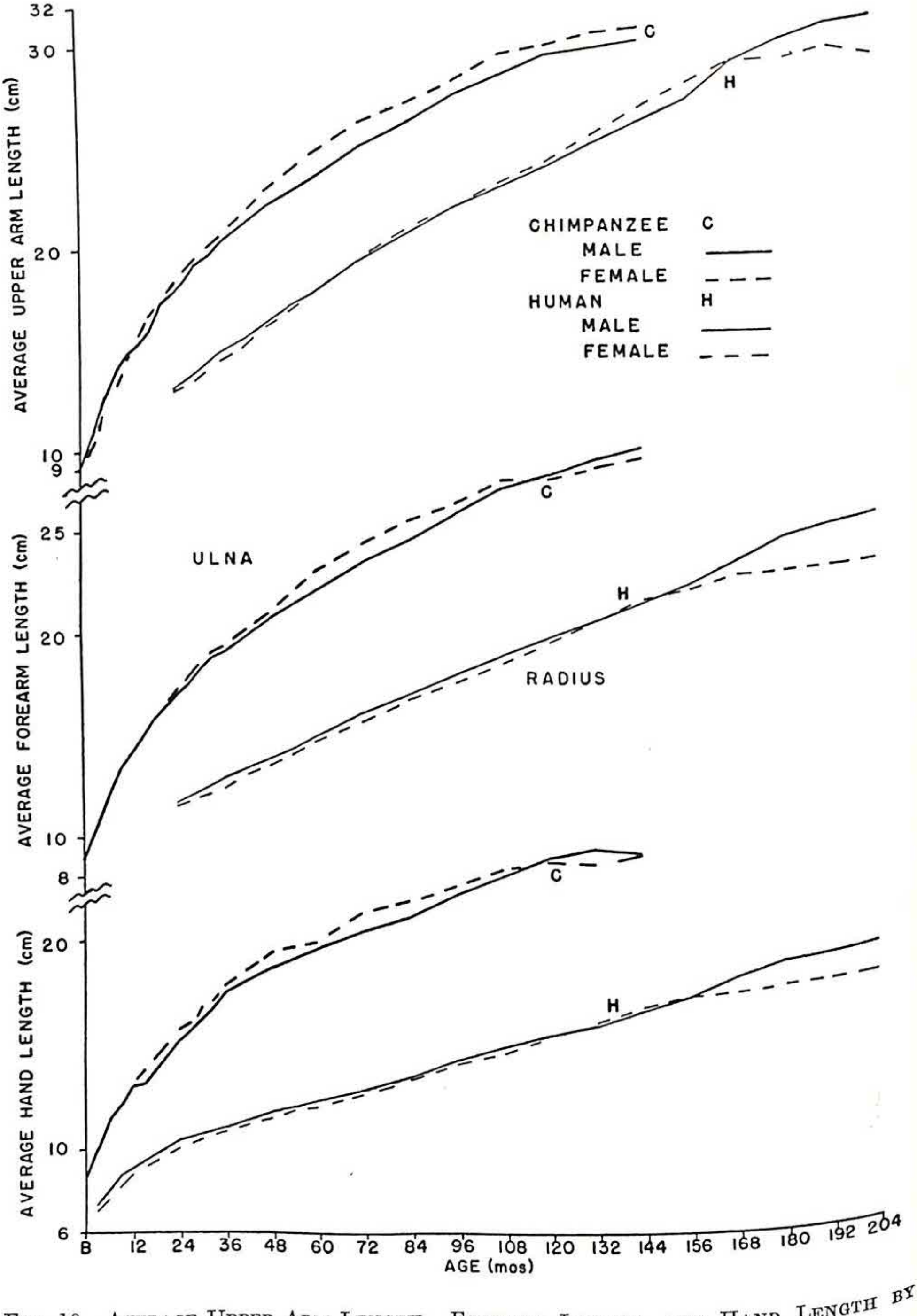


Fig. 10. Average Upper Arm Length, Forearm Length, and Hand Length by Chronological Age.

shape of the growth curves is different; each of the human curves has a period of approximately equal annual increments. The difference in the shape of the growth curves and in the duration of the growth period result in changes in the comparative length of these segments. A few comparisons will illustrate this point.

By expressing the human as a percent of the chimpanzee value the following tabulation is obtained:

	2 YEARS		5 YEARS		ADULTHOOD	
	M	F	M	F	M	F
Upper arm length	74.0%	71.0%	76.1%	73.4%	103.6%	97.4%
Hand length	67.5%	64.3%	63.4%	60.4%	79.5%	74.8%

There is a greater difference during growth than in adulthood; for upper arm length, there is virtually no species difference once growth ceases. The hand, however, does not show a consistent trend as there is a greater difference at 5 years than at either two years or adulthood. Chimpanzees grow faster, but human children grow for a longer period of time.

Unfortunately a direct comparison cannot be made for forearm length. The figures for chimpanzee ulna have been plotted with those of human radius to show that the shape of these curves is the same as in the other two segments. At 12 years both ulna and radius lengths were taken on three males and two females. The average radius length is 27.1 cm and 27.7 cm, male and female respectively. The adult human are 93.4% and 83.0% of these values. Taking these radius figures in conjunction with those of the upper arm and hand, it is seen that at adulthood the greater species difference is in the more distal segments; upper arm shows practically no difference; chimpanzee radius is longer than human radius, but the greatest length difference occurs in the hand.

In the lower extremity the situation is somewhat different (fig. 11). Here the human measurements are generally longer than the chim- panzee's although there is the same distinction in the shape of the curves.

Leg length and knee height are apparently longer in human children right from birth, in neither case do the species curves cross. Early in life, thigh length shows no species difference, but the chimpanzee's more rapid initial growth makes them the larger from 2 to 4 years. As the chimpanzee's rate decreases, while the human rate remains constant, the two species become approximately the same for the next two years when the human child gradually goes ahead.

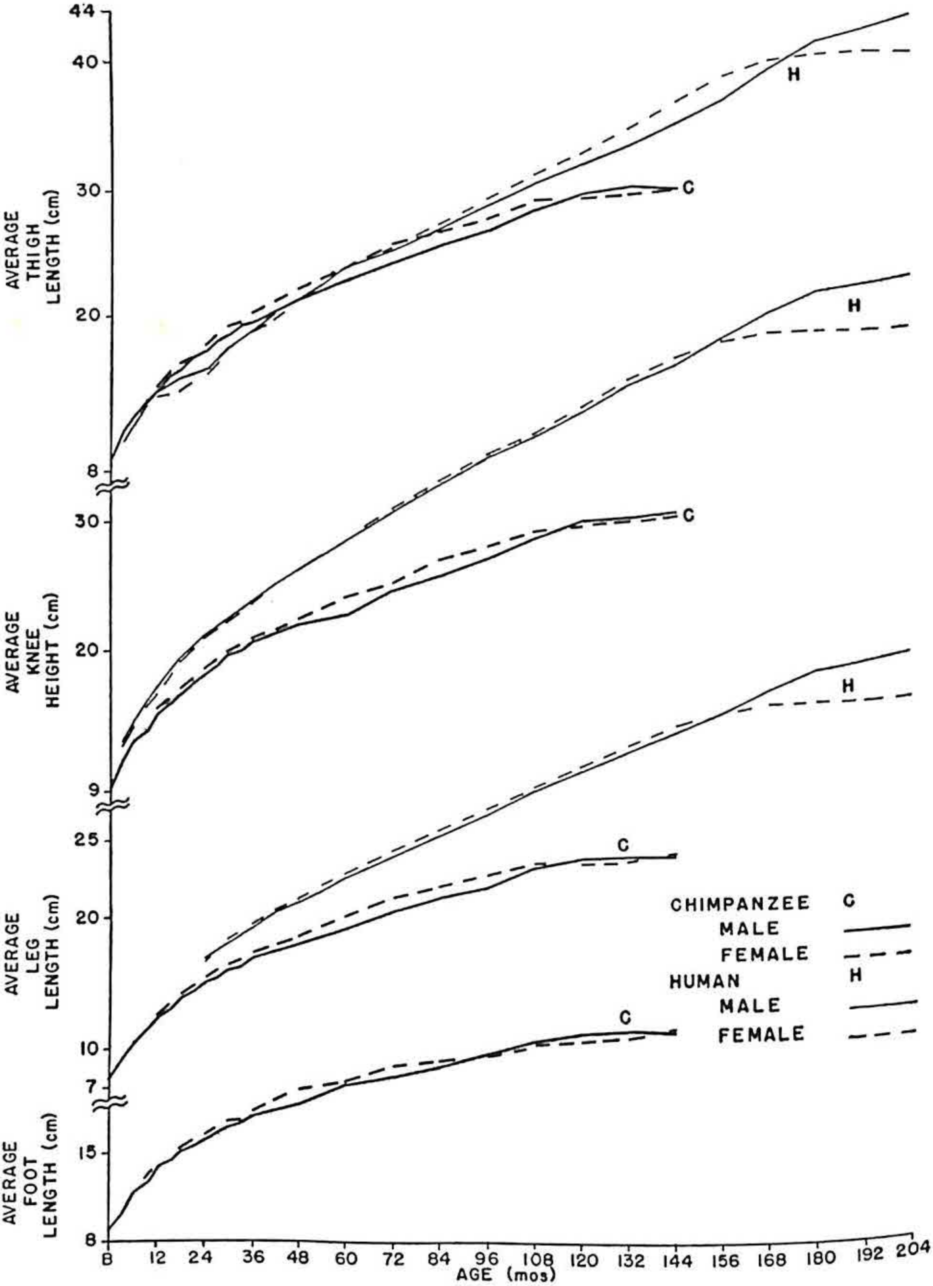


FIG. 11. AVERAGE THIGH LENGTH, KNEE HEIGHT, LEG LENGTH, AND FOOT LENGTH BY CHRONOLOGICAL AGE.

Foot length was not measured in the Brush study, but a human, adult male value may be estimated from Munro's nomograph (Munro, '52, p. 13). From the Brush adult male, average stature and weight, an estimated mean foot length of 26.6 ± .88 cm was obtained. Using this value a comparison of the extremities (100 × human/ chimpanzee) may be made.

MALES AT ADULTHOOD

Upper arm length	103.6%	Thigh length	144.0%
Forearm length	93.4%	Leg length	161.0%
Hand length	79.5%	Foot length	109.9%

Chimpanzees have a longer upper extremity while humans have a longer lower extremity, but in neither case do all the segments equally reflect this difference. The chimpanzee gets his longer upper extremity from his hand while the human gets his longer lower extremity from both the femur and tibia, more from the latter than from the former.

DEVELOPMENT: EXTREMITIES

The developmental relation between total arm length (sum of average upper arm, forearm, and hand lengths) and trunk height is shown in figure 12. There is a large difference between the species in total arm length at any given trunk height, but the sex difference within the species is small. At 28 cm trunk height, the human total arm length is 70.2% of the chimpanzee's; at 44 cm trunk height, the percentage is 78.0%. The sex ratio (100 × female/ male) at 28 cm trunk height is 98.2% for chimpanzees and 98.8% for human children. At 44 cm trunk height, these percentages have become 97.2% and 99.7% respectively.

In all 4 groups, total arm length increases a little less than two units for every unit increase in trunk height; total arm length increases faster than trunk height, but the comparative rate remains constant throughout the growth period. The significance of the differences in the b's shows no sex difference in rate for human children but a significant difference in size; chimpanzee sexes differ in rate and increase significantly faster than human children.

Lower extremity length (average thigh length plus average knee height) is plotted against trunk height in figure 13. A comparison of the b-values shows the more rapid comparative rate of lower extremity growth in humans; 2.29 boys and 2.36 girls, whereas the same values

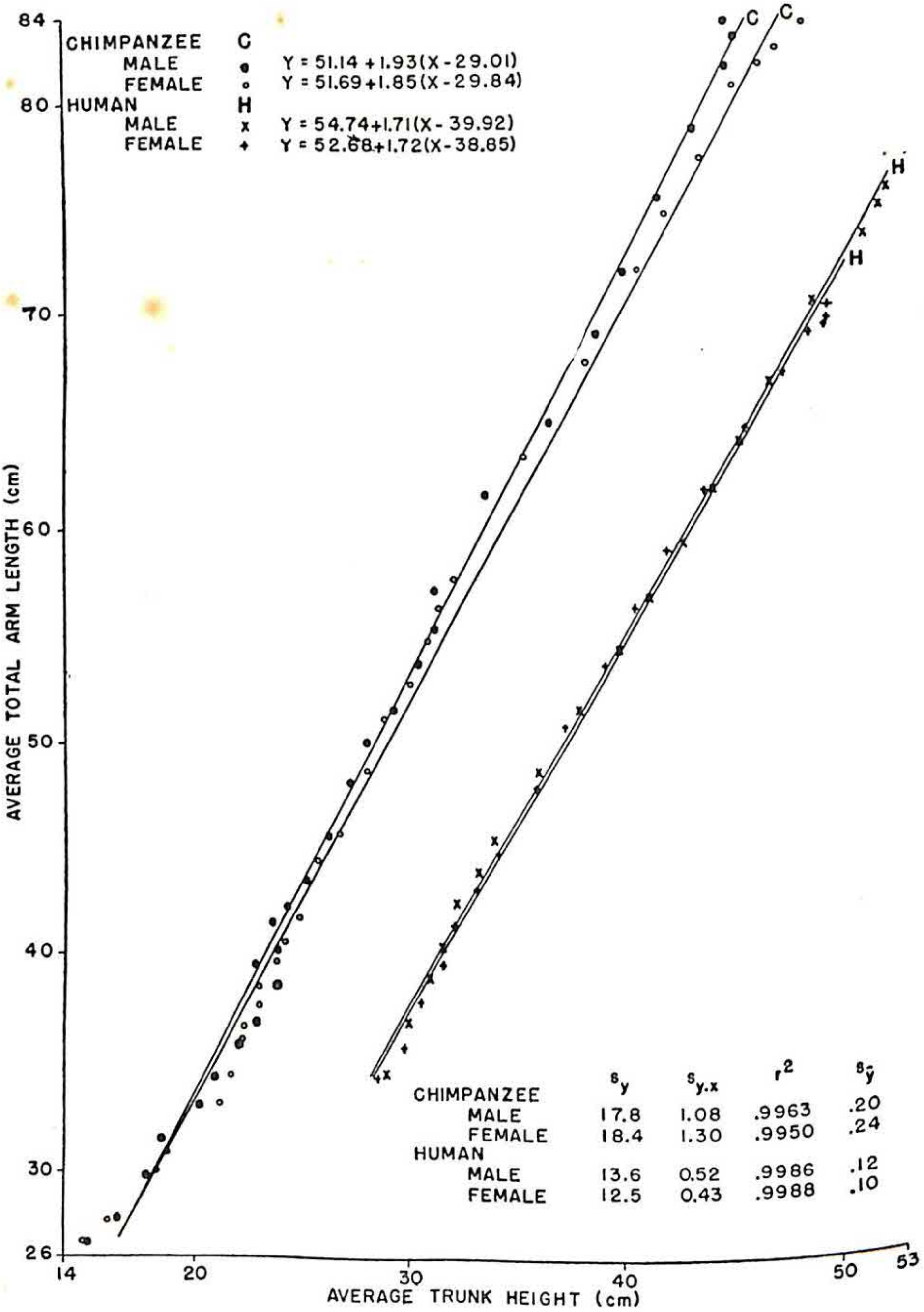


FIG. 12. REGRESSION OF AVERAGE TOTAL ARM LENGTH ON AVERAGE TRUNK HEIGHT.

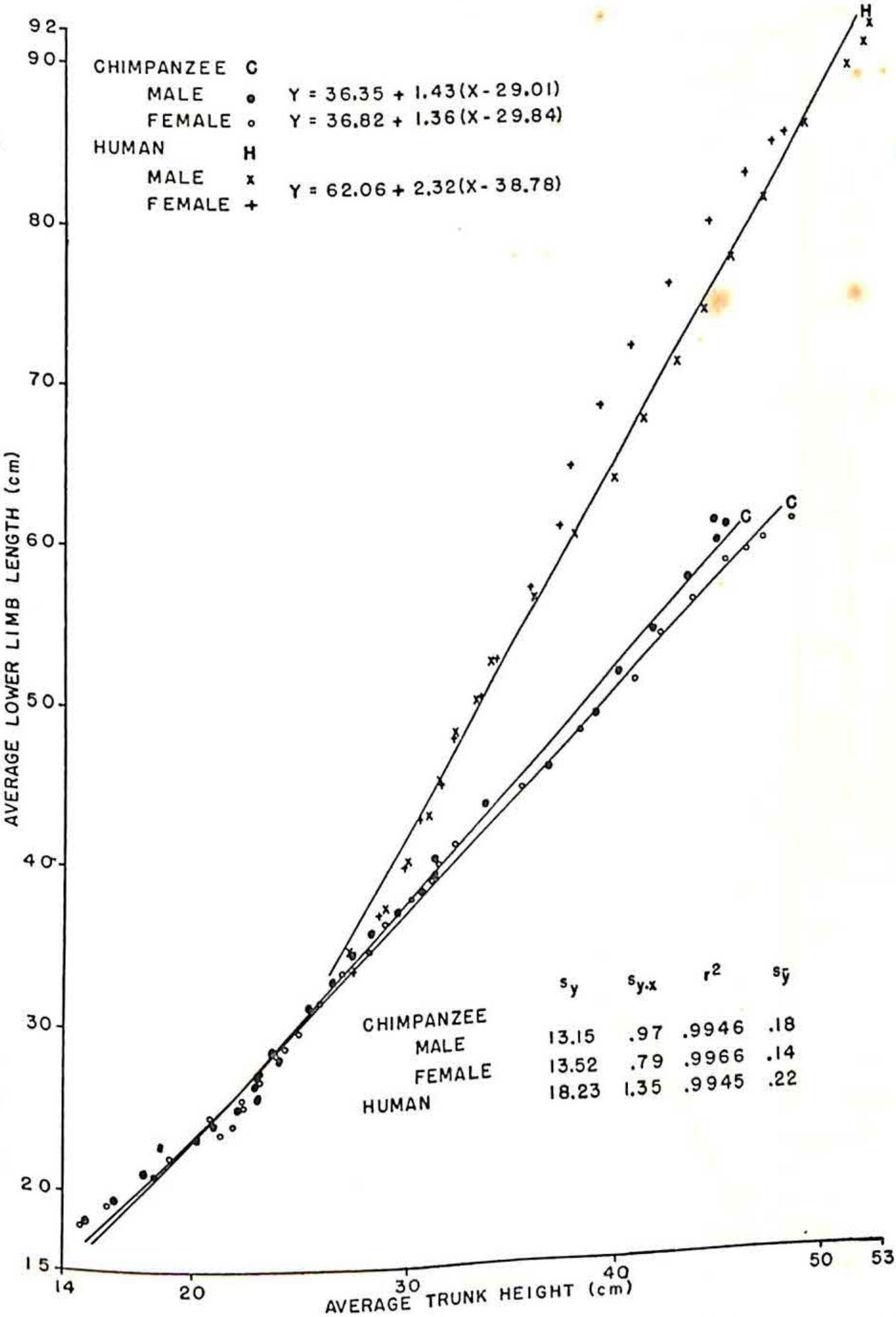
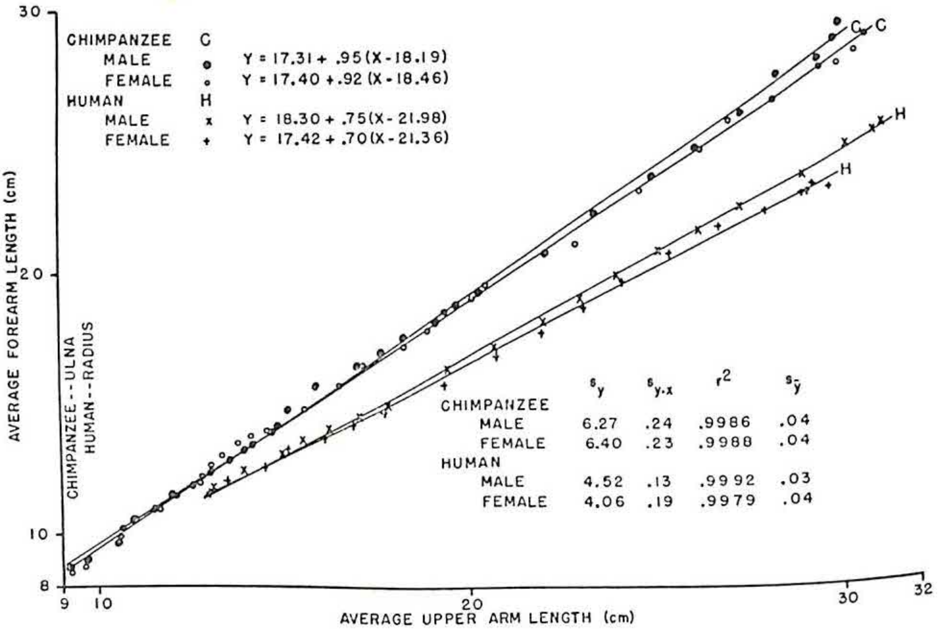


Fig. 13. Regression of Average Lower Limb Length on Average Trunk Height.

for chimpanzees are only 1.43 and 1.36. The t-tests show no human sex difference for either rate or size, but a well marked difference both between the species and between the chimpanzee sexes.

The relations between the segments of the limbs are given in the linear regression equations in figures 14 through 17. Although for forearm length, ulna was measured in chimpanzees and radius in the Brush children, this technique difference should change only the absolute size of the comparison but not the comparative rate of the two dimensions. Therefore, the curves in figure 14, forearm compared to upper arm, are comparable with respect to rate. Within each species, males grow more rapidly than females; chimpanzees grow more rapidly than human children.



	s_y	$s_{y.x}$	r^2	$s_{\bar{y}}$
CHIMPANZEE				
MALE	6.27	.24	.9986	.04
FEMALE	6.40	.23	.9988	.04
HUMAN				
MALE	4.52	.13	.9992	.03
FEMALE	4.06	.19	.9979	.04

FIG. 14. REGRESSION OF AVERAGE FOREARM LENGTH ON AVERAGE UPPER ARM LENGTH.

Growth of hand length in terms of forearm length (fig. 15), shows no significant sex difference in rate within either species, but both show a significant size difference, females larger than males. In the species comparison, chimpanzee hand length in terms of forearm length increases significantly faster than that of human children.

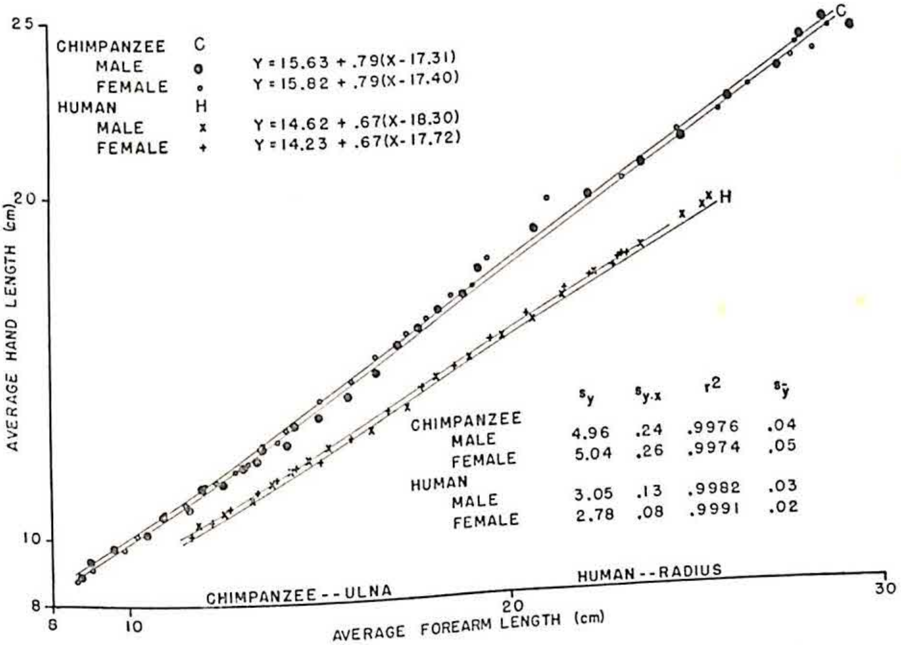


FIG. 16. REGRESSION OF AVERAGE LEG LENGTH ON AVERAGE THIGH LENGTH.

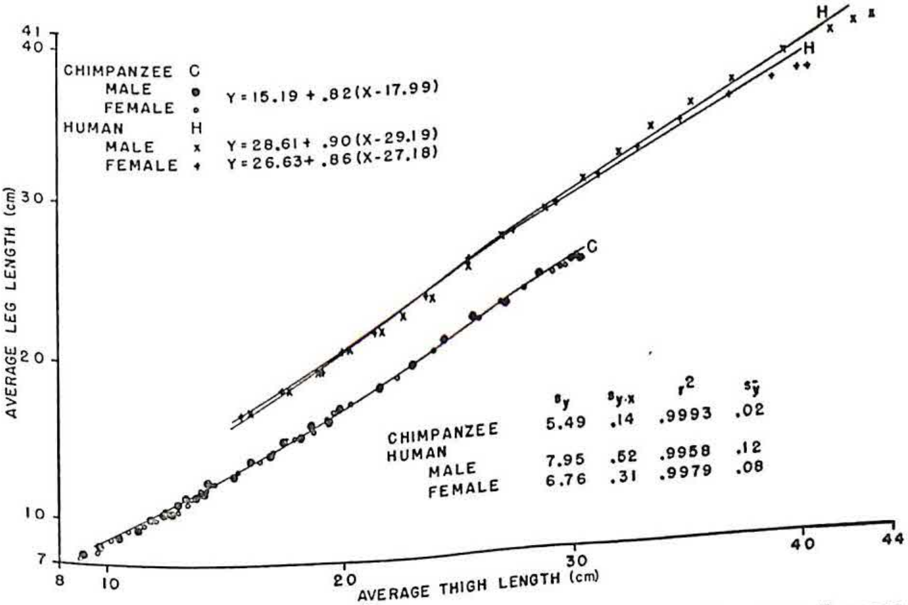


FIG. 15. REGRESSION OF AVERAGE HAND LENGTH ON AVERAGE FOREARM LENGTH.

There are no chimpanzee sex differences in either rate or size for growth of leg length in terms of thigh length (fig.16). The human sexes show a significant difference in rate, and both increase faster than the chimpanzee.

For foot length in terms of leg length, only the chimpanzee sexes can be compared. These show no difference in either rate or size so the sexes have been combined (fig. 17).

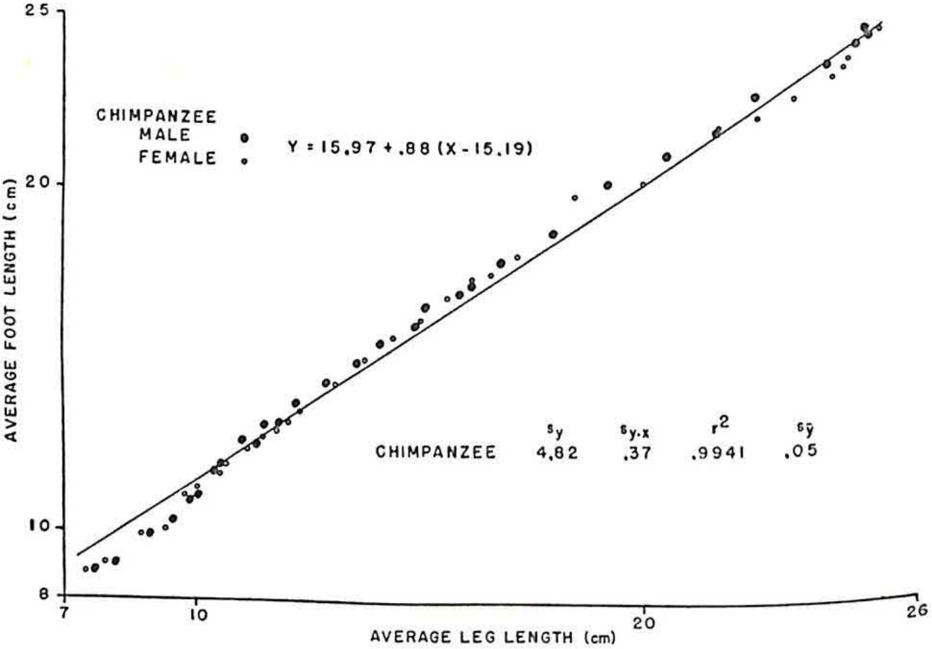


FIG. 17. REGRESSION OF AVERAGE FOOT LENGTH ON AVERAGE LEG LENGTH.

Increase of total arm length in terms of total leg length (fig. 18) for chimpanzees shows no significant difference in either rate or size; the human sexes differ in size, but not in rate. The chimpanzee total arm length increases significantly faster than does the human.

SUPPLEMENTARY RELATIONS

In the previous sections, regression was used to depict relations usually studied by an index. In most instances the independent variable was trunk height, but for the segments of the limbs, some other variable was used. Because comparisons can more easily be made in terms of a common base, the regressions of these segments against trunk height have been calculated (table 4).

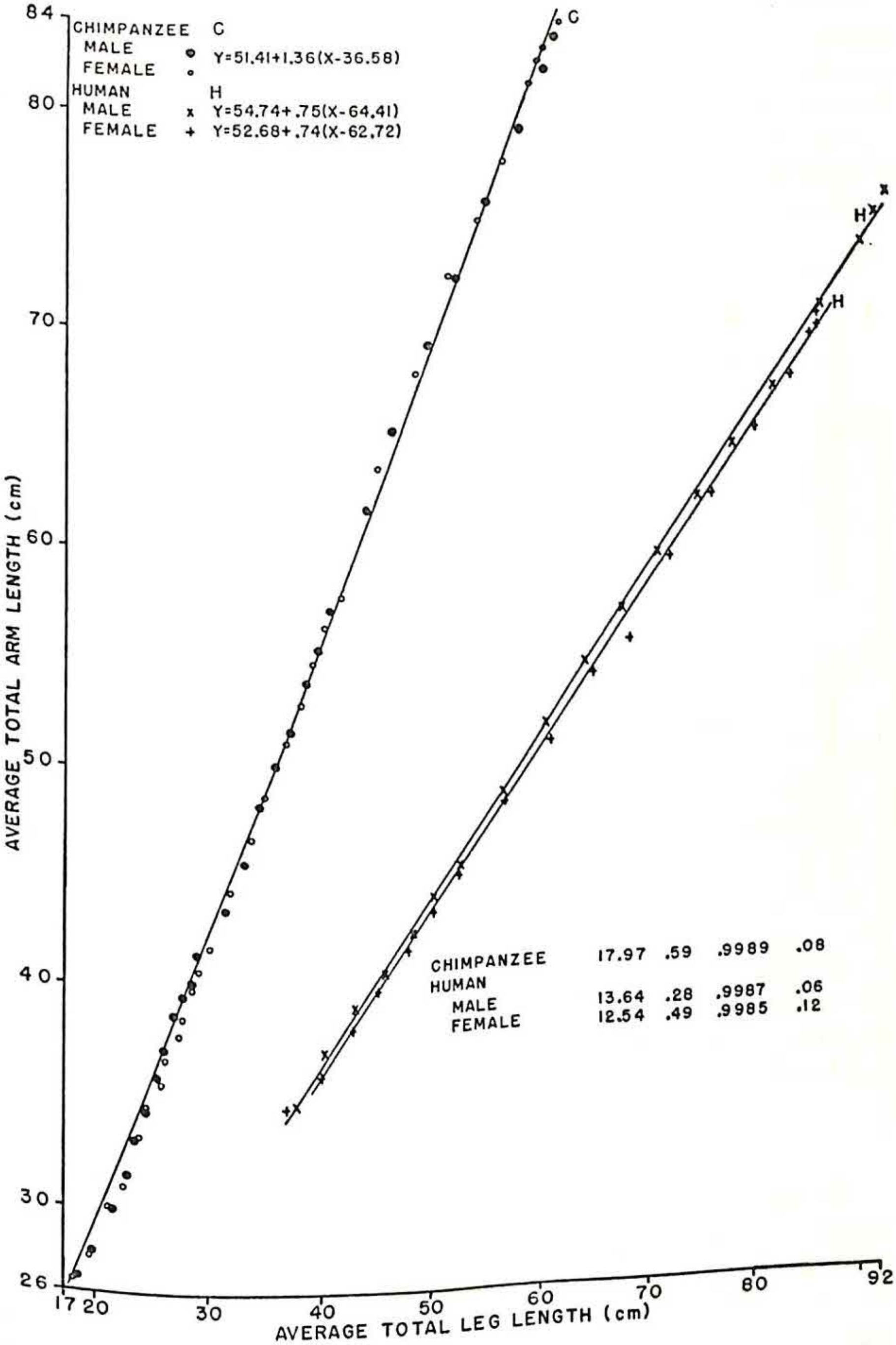


Fig. 18. Regression of Average Total Arm Length on Average Total Leg Length.

TABLE 4

Constants for the linear regression equations of dimension (Y) against trunk height (X)

DIMENSION (Y)	GROUP	SEX	a^*	b	r^2
Upper arm lgt.	Chimpanzee	M	—2.57	0.72	0.9964
		F	—2.50	0.70	0.9951
	Human	M	—8.30	0.76	0.9982
		F	—9.54	0.80	0.9954
Forearm lgt.	Chimpanzee	M	—2.41	0.68	0.9955
		F	—1.82	0.64	0.9956
	Human	M	—4.32	0.57	0.9990
		F	—4.24	0.56	0.9970
Hand lgt.	Chimpanzee	M	0.02	0.54	0.9953
		F	0.72	0.51	0.9915
	Human	—	—0.67	0.38	0.9961
Thigh lgt.	Chimpanzee	M	—2.97	0.72	0.9940
		F	—2.26	0.68	0.9962
	Human	M	—14.68	1.10	0.9963
		F	—17.13	1.18	0.9958
Leg lgt.	Chimpanzee	M	—2.07	0.59	0.9947
		F	—1.56	0.56	0.9957
	Human	M	—11.10	1.00	0.9961
		F	—11.89	1.03	0.9928
Foot lgt.	Chimpanzee	M	0.63	0.53	0.9953
		F	1.47	0.49	0.9887
Head lgt.	Chimpanzee	M	6.66	0.20	0.9452
		F	6.89	0.18	0.9456
	Human	M	14.07	0.10	0.9763
		F	13.48	0.10	0.9663
Head brd.	Chimpanzee	—	6.21	0.12	0.9464
	Human	M	11.81	0.06	0.9586
		F	11.21	0.07	0.9583

$^*a = \bar{y} - b\bar{x}$

The values of b are of principal interest and are shown graphically in figure 19. In both the upper and lower extremity and in all 4 groups, the more distal segments have a lower comparative rate of growth than the more proximal segments. In chimpanzees these gradients parallel one another, with males always relatively faster than females. In humans, girls are relatively faster than boys in three of the 5 comparisons, thigh, leg, and upper arm lengths; there is no sex difference in hand length, and boys are more rapid only in the comparative rate of forearm growth.

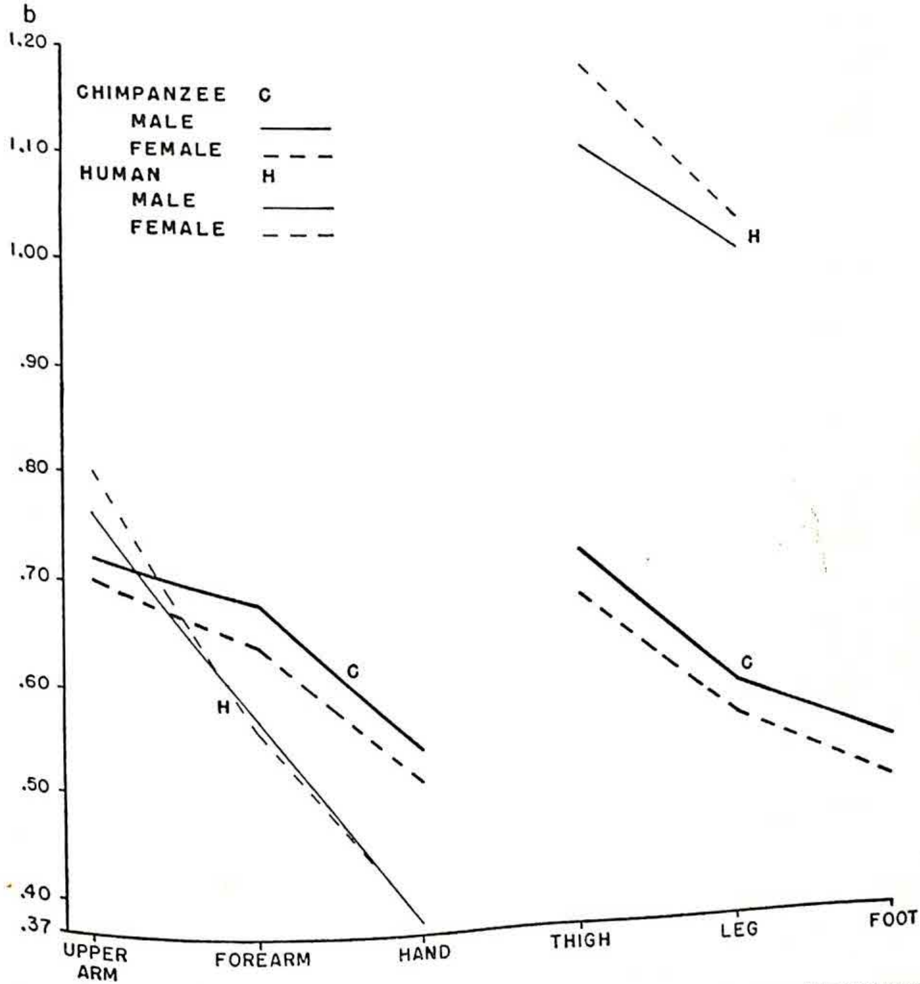


FIG. 19. VALUES OF b FOR THE REGRESSION OF EACH SEGMENT OF THE EXTREMITIES ON TRUNK HEIGHT.

In the species comparison, chimpanzees have the higher comparative rate only in forearm and hand. Although the differences in the upper extremity are all significant, they are not as pronounced as in the lower extremity where human thigh and leg grow approximately twice as fast as the chimpanzee's.

In a comparison of similarily placed segments of the two extremities, the human lower limb grows considerably faster than the upper limb, thigh 1.5 times faster than the upper arm and leg 1.8 times faster than the forearm. In chimpanzees there is no significant difference in rate between the thigh and upper arm or between the foot and hand in either sex. In both sexes the forearm grows faster than the leg.

GROWTH AND DEVELOPMENT: HEAD AND FACE

Growth of the head and face of the chimpanzee is represented by 4 measures, head length, head breadth, upper face height, and biorbital breadth. The means are plotted by chronological age in figure 20; comparative data from the Brush study are available only for head length and breadth.

All 4 measures in chimpanzees show very rapid initial growth. Head length, upper face height, and biorbital breadth during the first year have an average monthly increase of 3.0% to 3.5% while head breadth has an average monthly increase of 2.1%. For head length and breadth, human children from three to 12 months have an average monthly increase of between 2.0% and 2.3%. Chimpanzee head breadth increases slower, but head length increases faster than these same dimensions in human children.

The values of the head and face measurements at three months of age, youngest age for the Brush children, are expressed as a percent of their adult size, maximum size attained during the study, in table 5. In both species at three months, head breadth has attained relatively more of its final size than has head length. In both of these dimensions the human child has relatively less growing yet to do than has the chimpanzee infant.

In facial dimensions, chimpanzee biorbital breadth is relatively closer to its adult size than is upper face height, but both facial dimensions have relatively more growing yet to do than has either head diameter.

The chimpanzee's initially rapid head and face growth quickly decelerates but continues a slow increase until 12 years. All 4 measures for chimpanzee may really have reached a plateau by this time, but the

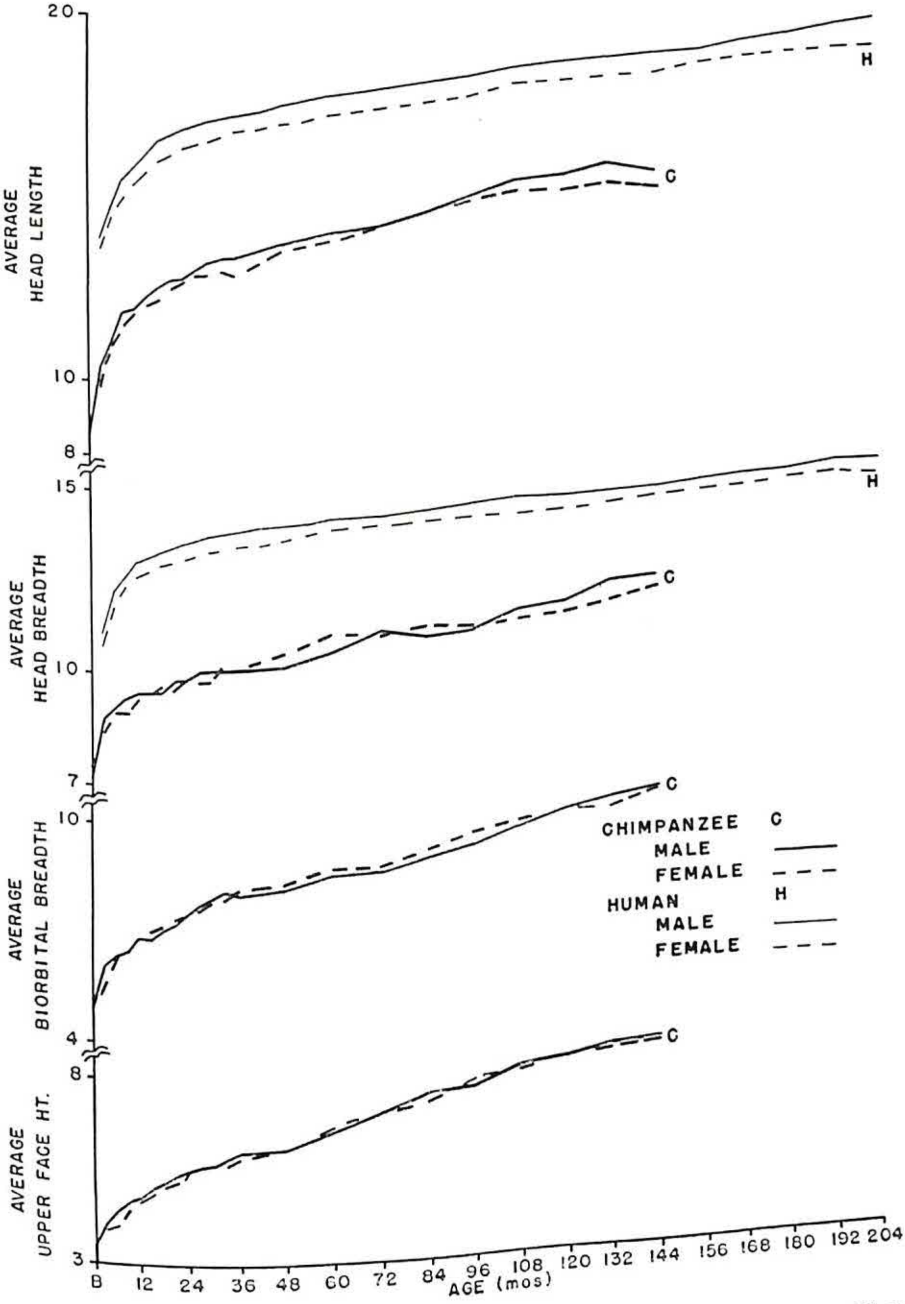


FIG. 20. AVERAGE HEAD LENGTH, HEAD BREADTH, BIORBITAL BREADTH, AND UPPER FACE HEIGHT BY CHRONOLOGICAL AGE.

TABLE 5

Head and face measurements for the Normative Group of chimpanzees and for human children (Brush) at three months expressed as a percent of their adult size

	CHIMPANZEE		HUMAN	
	Male	Female	Male	Female
Head length	65.6	66.4	71.1	72.5
Head breadth	71.9	70.3	73.0	72.2
Biorbital breadth	57.2	52.9	——	——
Upper face height	48.5	45.6	——	——

sample, being small, does not indicate this definitely. By 17 years, the human male curve for head length is still increasing slowly, but head breadth and the two female curves have apparently reached their plateau.

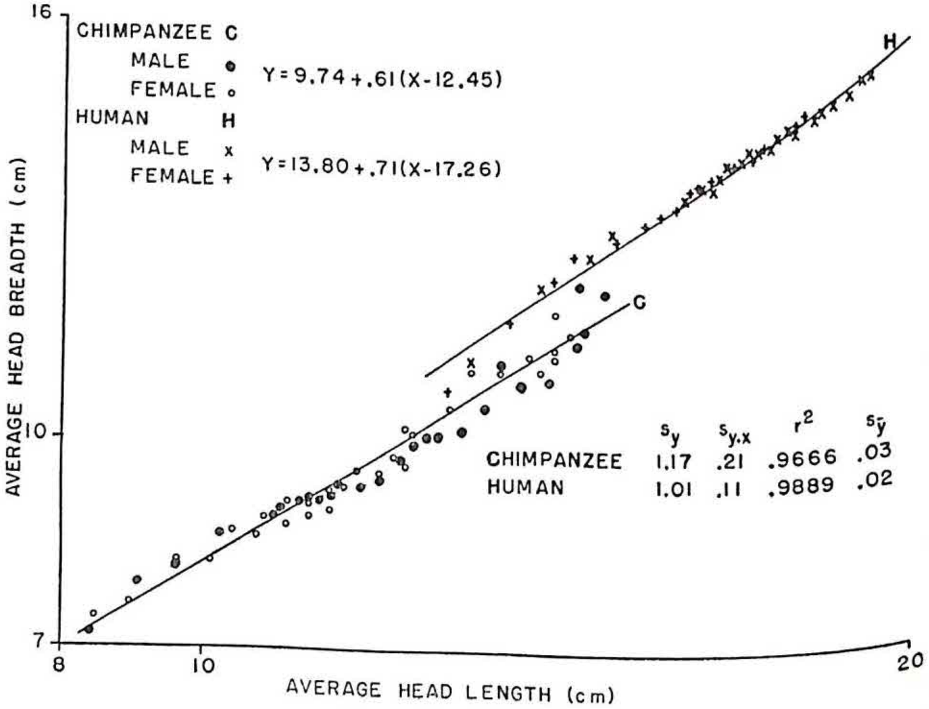


FIG. 21. REGRESSION OF AVERAGE HEAD BREADTH ON AVERAGE HEAD LENGTH.

Regression shows a very consistent relation between head length and breadth (fig. 21). In neither species is there a significant sex difference in either rate or size. There is a significant difference between the species with breadth as compared to length increasing faster in humans than in chimpanzees.

Both head length and head breadth were studied with respect to trunk height (table 4). In both dimensions chimpanzees have a comparative rate almost twice that of human children. Whether this difference is due to brain, frontal sinus, or bone growth cannot be determined from these data. If the development of the supraorbital torus, which contributes to head length, is in response to masticatory pressures (see Weinmann and Sicher, '47, p. 118) then head length is, at least in part, a measure of facial growth. Washburn ('42a, '42b, '43, and '53) has repeatedly emphasized the dangers inherent in phylogenetic comparisons of external diameters when the internal anatomy is unknown. In the present instance the data simply indicate that these dimensions of the head grow at a constant, comparative rate with respect to one another in both species.

DISCUSSION

The preceeding analysis has indicated a number of differences in growth pattern both between chimpanzee and man and between the sexes within each species. Two of these differences are apparent in trunk height growth (figs. 5 and 6). The original diversity in the 4 curves practically disappears when age and final size are equated, indicating that the diversity is due to differences in length of the growth period and to differences in final size. However, this curve of trunk height growth is curvilinear with respect to the equated age scale and is, therefore, difficult to analyze in any simple manner. It does show that the pattern of trunk height growth, independent of the length of the growth period and of final, absolute size, is basically the same in the two species and sexes. In order to determine what other differences there may be, the method of comparison should not re-analyze the two already identified.

The index method does not satisfy this criterion. The index, plotted against chronological age, is not independent of the length of the growth period. Even if this were equated, the curve would not be linear and would show chance fluctuations which would have to be smoothed in some manner. These difficulties disappear when a regression equation is used. The parameter *b* not only is independent of the absolute size of the dimensions but also affords a simple means of comparing rate of growth when the same measure of linear size is used as the independent variable.

The selection of trunk height as this measure of linear size stems from the similarity of the sex and species curves when total growth time and final adult size are eliminated as variables. Therefore, the study of the growth of each dimension in terms of trunk height by means of simple, linear regression shows the similarities and/or differences which are independent of the differences in adult, trunk height size and the duration of chronological time necessary to attain that size.

Considered in this manner, the growth changes between birth and maturity lose their complexity and instead there is regularity of change and constancy of direction. At least from birth, the primate organism in the dimensions considered pursues a single course of growth to its completion at adulthood.

For a consideration of the various regression equations, table 6 summarizes the levels of confidence for all significant differences in comparative rate and in size. The first column lists the variables of the equations; the second gives the groups compared (chimpanzee versus human or the sexes within the species). The third column shows the level of confidence for the species difference in comparative rate and the group with the more rapid growth (B for Brush and C for chimpanzee). The fourth gives the level of confidence for the significance of the difference between the sexes of each species in rate and the sex with the more rapid growth (M for male and F for female). The last column indicates the level of significance of the size difference, when no rate difference is found, and also indicates the larger sex.

In the species comparison all rate differences are significant. With the exception of the cube root of weight/trunk height both chimpanzee sexes differ from both human sexes at the 1% level of confidence; in this one case male chimpanzees differ from boys at the 2% level. This indicates that even if the independent variable had been the same in both species, they would still have become more different as growth progressed. The absolute differences in the limbs, hips, and head are not just repetitions of differences in linear body size but are additional and independent.

The comparative rate with respect to trunk height shows that human children grow faster in weight, lower extremity length, and hip breadth; they are slower in head length, head breadth, and total arm length. In the segments of the lower extremity, human children are always faster,

TABLE 6

Levels of confidence for differences in comparative rate (b) and size in the various regression equations

Dependent / Independent Variable	LEVEL OF CONFIDENCE		
	Comparative Rate		Size
	Species	Sex	
Cube Root of Wt./Trunk Ht.			
Species	2% −1% B	....	....
Chimpanzee	....	1% M	....
Human	....	N.S.*	N.S.
Total Arm Lgt./Trunk Ht.			
Species	1% C	....	....
Chimpanzee	....	2% M	....
Human	....	N.S.	5% M
Upper Arm Lgt./Trunk Ht.			
Species	1% B	....	....
Chimpanzee	....	N.S.	1% M
Human	....	1% F	....
Forearm Lgt./Trunk Ht.			
Species	1% C	....	....
Chimpanzee	....	1% M	....
Human	....	N.S.	1% M
Hand Lgt./Trunk Ht.			
Species	1% C	....	....
Chimpanzee	....	1% M	....
Human	....	N.S.	N.S.
Forearm/Upper Arm Lgt.			
Species	1% C	....	....
Chimpanzee	....	1% M	....
Human	....	1% M	....
Hand Lgt./Forearm Lgt.			
Species	1% C	....	....
Chimpanzee	....	N.S.	1% F
Human	....	N.S.	1% F
Total Leg Lgt./Trunk Ht.			
Species	1% B	....	....
Chimpanzee	....	1% M	....
Human	....	N.S.	N.S.
Foot Lgt./Trunk Ht.			
Chimpanzee	....	1% M	....
Thigh Lgt./Trunk Ht.			
Species	1% B	....	....
Chimpanzee	....	1% M	....
Human	....	1% F	....
Leg Lgt./Trunk Ht.			
Species	1% B	....	....
Chimpanzee	....	1% M	....
Human	....	N.S.	5% F
Leg Lgt./Thigh Lgt.			
Species	1% B	....	....
Chimpanzee	....	N.S.	N.S.
Human	....	5% M	....
Foot Lgt./Leg Lgt.			
Chimpanzee	....	N.S.	N.S.
Total Arm/Total Leg Lgt.			
Species	1% C	....	....
Chimpanzee	....	N.S.	N.S.
Human	....	N.S.	1% M
Hip Brd./Trunk Ht.			
Species	1% B	....	....
Chimpanzee	....	N.S.	N.S.
Human	....	1% F	....
Head Lgt./Trunk Ht.			
Species	1% C	....	....
Chimpanzee	....	N.S.	1% M
Human	....	N.S.	1% M
Head Brd./Trunk Ht.			
Species	1% C	....	....
Chimpanzee	....	N.S.	N.S.
Human	....	5% F	....
Head Brd./Head Lgt.			
Species	1% B	....	....
Chimpanzee	....	N.S.	N.S.
Human	....	N.S.	N.S.

*N.S.—difference is not significant.

but for the segments of the upper extremity chimpanzees are the faster only in forearm and hand length; human children have the higher rate in upper arm length. This points again to the conclusion that the chimpanzee gets his longer upper extremity from more rapid growth in the forearm and hand rather than from the upper extremity as a whole.

Of the 9 regressions against trunk height (total limb lengths not considered), 5 for Brush and 4 for chimpanzee show no sex difference in comparative rate; of these, each species has no size difference in two dimensions. The two species show about the same amount of sex similarity, but they show it in different dimensions. With trunk height constant, human children show no sex difference in weight or in hand length; chimpanzees show no sex difference in hip or head breadth. Therefore, absolute sex differences in these dimensions are associated with differences already observed in trunk height.

Throughout the analysis, the dimensions were considered singly or in pairs. In order to bring the dimensions together and present a picture of growth and development of the body as a whole, figures 22 and 23 were prepared. These figures represent, diagrammatically, 9 measurements, in their relative anatomic position, of chimpanzee and human, male and female children at 4 stages in their growth period: birth, end of infancy, puberty, and adulthood. Data were not always available at the exact age marking the boundary between these subdivisions of the total growth period; therefore, data of the nearest chronological age were used as indicated. In both figures the width of the shoulders is arbitrary as there is no measure of biacromial breadth for chimpanzees.

The increase in absolute size from birth to adulthood can be seen in figure 22. The chimpanzeee's smaller, linear body size, longer upper extremity, and shorter lower extremity are apparent. The increase in the size difference between the human sexes can be compared with the no less real, but far less apparent, sex difference in the chimpanzee. However, differences in one dimension may augment or obscure differences in another so figure 23 was constructed.

In figure 23, the lengths of the various dimensions have been calculated from their regression on trunk height. At each stage the trunk height of the average male chimpanzee was used for all 4 groups. These diagrams show what each of the 4 groups would have been like if in each the trunk height had been the same as that of the male chimpanzee.

A number of otherwise obscured differences are now apparent. At birth both chimpanzee sexes show the relatively long upper extremities characteristic of adulthood. However, at this same time, they also have

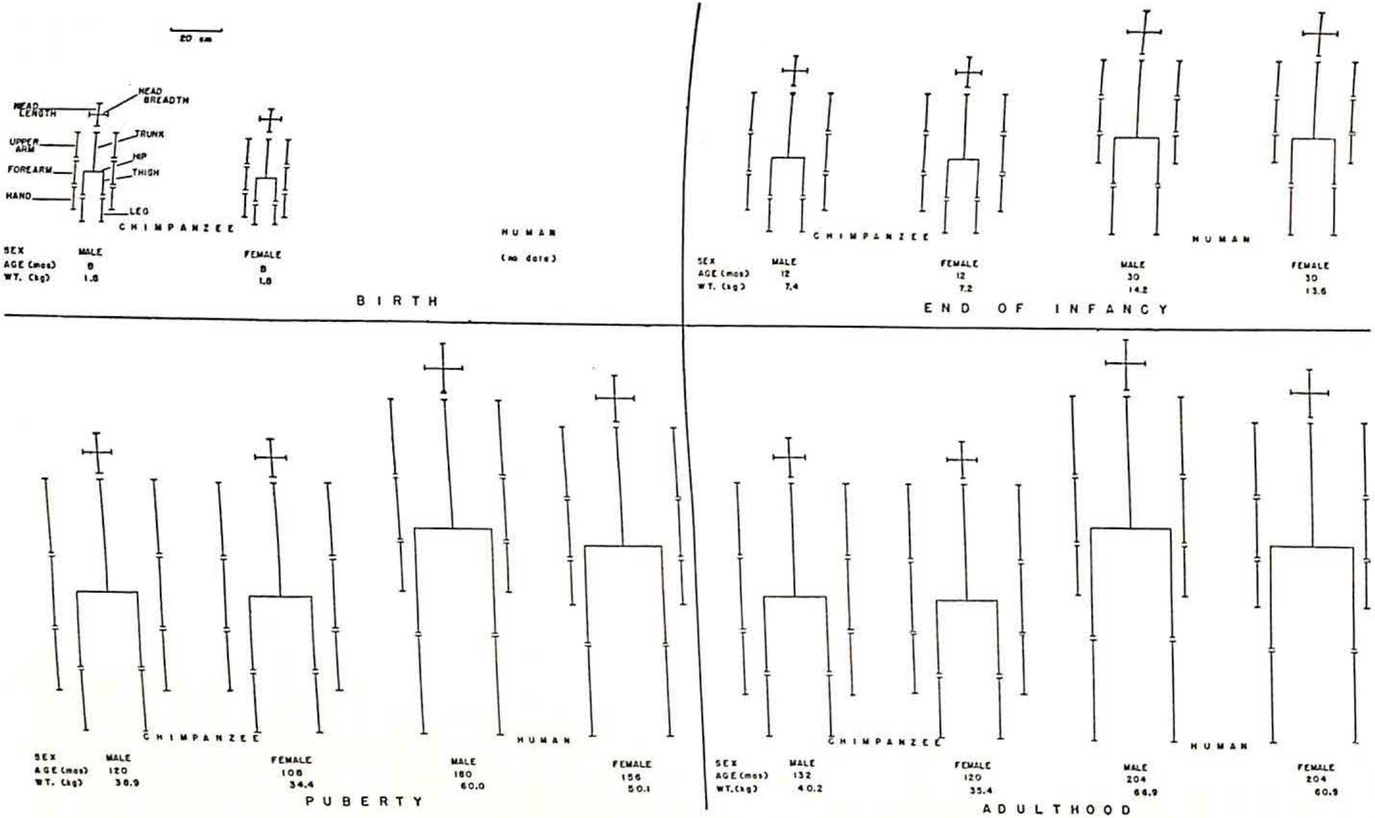


FIG. 22. SIZE OF THE MALE AND FEMALE CHIMPANZEE AND HUMAN (BRUSH) CHILDREN SHOWN DIAGRAMMATICALLY AT FOUR POINTS IN THE TOTAL GROWTH PERIOD.

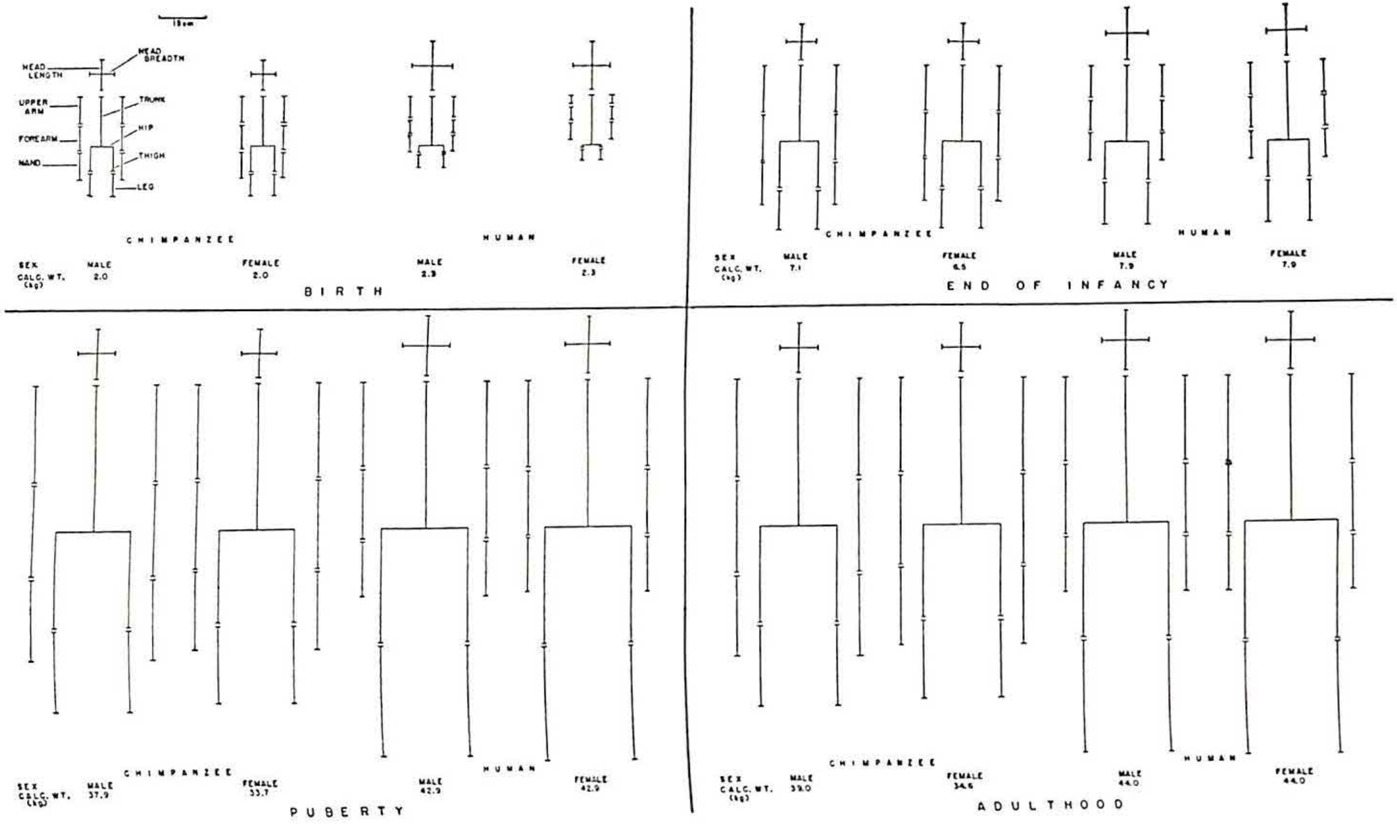


FIG. 23. DIAGRAMMATIC REPRESENTATION OF THE GROWTH AND DEVELOPMENT OF THE MALE AND FEMALE CHIMPANZEE AND HUMAN (BRUSH) CHILDREN. AT EACH STAGE THE LENGTHS OF THE DIMENSIONS WERE CALCULATED FROM THE APPROPRIATE REGRESSION ON TRUNK HEIGHT. THE VALUE OF TRUNK HEIGHT USED, FOR EACH STAGE, WAS THAT OF THE AVERAGE MALE CHIMPANZEE.

relatively much longer lower extremities than do human children. In this context, the human newborn child has relatively short extremities; the condition of the upper extremity remains unchanged during growth so that at adulthood, as at birth, human arms are shorter than chimpanzee's arms. The major change is in the legs where the much higher human comparative rate produces a longer legged adult.

Another interesting comparison is in head size as determined by head length and breadth. At all stages the human head is relatively larger than the chimpanzee's, but the difference is greatest at birth and least at adulthood. At birth the difference in head length is over 5 cm, while at adulthood it is less than 3 cm. Breadth at birth shows a difference of over 4 cm, but at adulthood this is reduced to less than 3 cm. Although the chimpanzee increases his head size relative to linear body size faster than does the human child, at any given trunk height the human child has the absolutely larger head.

SUMMARY AND CONCLUSION

The purpose of this paper is to identify and analyze resemblances and differences between chimpanzee and man during growth and development.

The basic, longitudinal data were obtained from 16 chimpanzees born and raised at the Yerkes Laboratories of Primate Biology. For certain problems supplementary data from other laboratory animals are also used. Comparative human data are from Simmons' ('44) report on the Brush Foundation children.

Consideration of the total growth period, conception to completion of linear growth, indicates that chimpanzees require less time to complete their growth than humans and that females require less than males. This is true not only for the total period, but also for its postnatal subdivisions: infancy, childhood, and adolescence. When the subdivisions are expressed as a percent of the total growth period, sex differences practically disappear. These percentages also indicate that the chimpanzee gestation period and childhood are relatively longer while infancy and adolescence are relatively shorter than in human children. The difference is not great and perhaps is not significant. In a relative sense the timing of events within the total growth period is very likely the same for both species.

The analysis of weight indicates that at birth chimpanzees are relatively smaller than human babies; the newborn chimpanzee weighs, on the average 4.25% of its mother's weight while the same figure for humans is 5.50%. The chimpanzee range overlaps the human average.

Using the maximum weight attained after 150 months as the measure of adult weight, the male chimpanzee averages 53.4 kg and the female 49.2 kg, but the heaviest female weighs more than the heaviest male.

Between birth and 144 months, there is considerable overlap between the sexes in the weight range, and on the average there is no sex difference until 30 months. Females are then heavier until 120 months when the males go ahead. Human children are heavier than chimpanzees at birth and adulthood, but chimpanzees are heavier between 4 and 12 years.

Annual weight increments show a decline after birth, followed by an increase to an age of maximum growth; this occurs in human children before but in chimpanzees after puberty. Because the age of maximum growth comes at approximately 70% of adult size in both sexes and species, it is suggested that the age of maximum growth may be indicative of approaching adulthood rather than being causally related to the events of puberty.

When the average chimpanzee data for each linear dimension are plotted against chronological age, the various growth curves have the same general form. The largest annual increment occurs immediately after birth; each subsequent increment is smaller than the preceeding. In weight and in all linear dimensions, with the exception of hip breadth, there is no sex difference in early infancy. In hip breadth, there is a sex difference at this time; the male is the larger. There follows a period, not of the same duration in all dimensions, where, in the post-cranium, the female is the larger sex. Because of her shorter growing period, the female does not retain this size superiority into adulthood except for trunk height and upper arm length. In all other post-cranial dimensions the male is the larger adult on the average.

Of the 4 head and face measurements there are indications of a sex difference only in head length. In the other dimensions there is apparently no sex difference even in the adults.

Trunk height was used as a measure of linear body size instead of stature, the usual measure in human studies. When plotted against chronological age, trunk height shows both species and sex differences. These differences were almost eliminated by expressing age as a percent of the total growth period and by expressing size as a percent of adult size. The two species and sexes differ in adult size and in the length of time required to reach that size, but the curves connecting these end points with conception are practically the same.

The other linear dimensions and weight also show species and sex differences. To determine if these differences are independent of those already identified in trunk height, each dimension and the cube root of average weight (rather than average weight itself) were plotted against trunk height, and the linear regression equations were determined.

Regression was preferred over the traditional indices in this case because, by using all of the data simultaneously, regression identifies the main trend of the data and gives a simple, more consistent picture of relative changes during growth. Simple linear regression was used in preference to more complex expressions because the coefficient of determination showed that only an insignificant amount of the original variability in the dependent variable was not associated with the variability in trunk height.

The regressions against trunk height showed that human children (as represented by the Brush data) have a higher comparative rate of growth in weight, hip breadth, total lower extremity length and each of its segments, and in upper arm length. The chimpanzee has the higher comparative rate in forearm length, hand length, total upper extremity length, head length, and head breadth. In each case the species difference was highly significant. Even if linear body size had been the same in these species, there would still have been significant differences in all the other bodily dimensions considered.

This methodology, regression of each dimension against trunk height, not only reduces the complex picture of growth depicted by indices to a series of simple straight lines, but also makes it possible to use trunk height as a comparative measure of growth. The organism, in the dimensions considered, follows, at least from birth, a single course of growth to completion at adulthood.

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SEX AND AGE DIFFERENCES IN THE COMPOSITION OF THE ADULT LEG

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INTRODUCTION

PHYSICAL anthropology has long been interested in the dimensional, structural and topological differences between the sexes, and in the divergent changes in form and structure associated with aging in men and women. Up to a decade ago these problems were attacked, for the most part, by anthropometric techniques, with an accumulation of information on size differences and size changes. During the last ten years the use of roentgenographic techniques has made it possible to go beneath the surface, and to trace the " internal contours " and their changes during the formative years (Reynolds, '52). Most recently attention has been directed toward the latter half of the life cycle (Keys, '53; Brožek and Keys, '50; Brožek, '52).

What happens in the aging adult is only poorly known, even in the male, and in our own culture. Weight increases up to the sixth decade (Hooton and Dupertuis '51). This may be attributed to a gain in fat, though after some point there must be a loss in muscle. Loss in dimensions other than stature, revealed by anthropometric techniques, may be due to loss of fat, or muscle, or both. Only in the increased size of the ears and nose have we a clear picture obtained by anthropometry alone of what happens to particular structures as age progresses.

Using indirect estimates of body composition, such as the specific gravity technique of Behnke and his associates ('42), or more direct measurements of subcutaneous fat, Keys and his group have established some illuminating facts (Keys, '53; Brožek and Keys '50, '51). In the aging male there is a progressive increase in fat, even with constant weight. But this is true only in a general way. On some parts of the body fat accumulates rapidly; elsewhere fat gain is slow (Garn, '53). Some masses of muscle may show a rapid decrease in age; other muscle groups may maintain their size for a long time. In some areas fat decreases at the same time that it increases elsewhere. Our present need is for exact information on when and where fat is gained, and when and how muscle is lost in adults of both sexes.

It is the purpose of this study, therefore, to investigate the problem of sex and age differences in tissue composition on one part of the body (the leg), in the age span 20–50 years. It is recognized that quantitative sex differences, and changes in composition associated with age may vary considerably according to the part of the body considered and the age span under investigation. In dealing with the lower leg, we are presenting data on one part of the body and neither suggest nor expect that these changes are characteristic of other body regions or the body as a whole.

MATERIALS AND METHODS

The present study is based on linear measurements of the muscle and fat shadows on lower limb X-rays of 50 adult males and 50 adult females, using standardized roentgenographic and mensurational techniques throughout.

The 100 subjects in this study were white, with few exceptions of northwest European origin, members of the semiurban middle-class population of southwestern Ohio. Ninety-one were parents of participants in the longitudinal growth studies, two had themselves been participants in the Fels longitudinal studies since birth, and 7 were members of the Fels Institute Staff.

The X-rays, of the left leg in every case, were taken antero-posteriorly at a standardized 6′ tube-to-film distance as described by Reynolds ('51). Exposures were constant at 20 millampere-seconds and peak kilovoltages ranged from 51 to 59 kv., as required by variations in limb thickness.

Measurements were taken at the level of the greatest muscle diameter, using a pinpoint vernier caliper (Fisher #12–130) calibrated to 0.1 mm. Muscle thickness was recorded as measured, while superficial tissue measurements of the lateral and medial aspects of the leg were recorded separately (fig. 1). Total fat and total tissue thickness (muscle plus fat) were obtained by addition.

It should be noted that the particular measurements taken are simple diameters, designed to show the extent of variations in muscle and fat

TABLE 1

Age and sex differences in transverse leg measurements: Means, standard errors, and confidence levels

MEASUREMENT	50 MEN	50 WOMEN	p[1] MEN VS. WOMEN	25 YOUNGER MEN	25 OLDER MEN	p[1] YOUNGER VS. OLDER MEN	26 YOUNGER WOMEN	24 OLDER WOMEN	p[1] YOUNGER VS. OLDER WOMEN
1. Age	39.2±1.3	34.5±1.6		32.0±1.1	46.3±1.3		25.8±1.0	44.0±1.6	
2. Muscle diameter	107.5±1.1	95.6±1.5	.001	108.3±1.7	106.7±1.4	.46	95.0±1.0	96.3±2.3	.60
3. Lateral fat	4.4±0.2	7.7±0.4	.001	4.5±0.4	4.2±1.3	.45	7.4±0.4	8.0±0.6	.40
4. Medial fat	5.1±0.4	11.3±0.7	.001	5.4±0.6	4.8±0.3	.37	9.6±0.7	13.1±1.2	.01
5. Total fat	9.5±0.6	19.0±1.0	.001	10.0±1.0	9.1±0.5	.42	17.0±1.0	21.1±1.7	.04
6. Total: fat plus muscle	117.0±1.3	114.6±1.9	.30	118.3±2.1	115.7±1.5	.36	112.0±2.0	117.4±3.3	.16
7. Fat as a percent of total	8.1±0.4	16.4±0.7	.001	8.3±0.7	7.8±0.4	.53	15.2±0.8	17.6±0.8	.07

[1] p indicates confidence levels for the differences observed. All p values were calculated from the formula $\frac{M_1 - M_2}{\sqrt{(se_1)^2 + (se_2)^2}}$ and table C in Guilford ('50).

thickness in the lower leg. No corrections for bone size were necessary, nor was there any purpose in converting the diameters into areas or volumes. No corrections were made for magnification, a constant factor and less than 2%, or for possible variations in epidermal thickness.

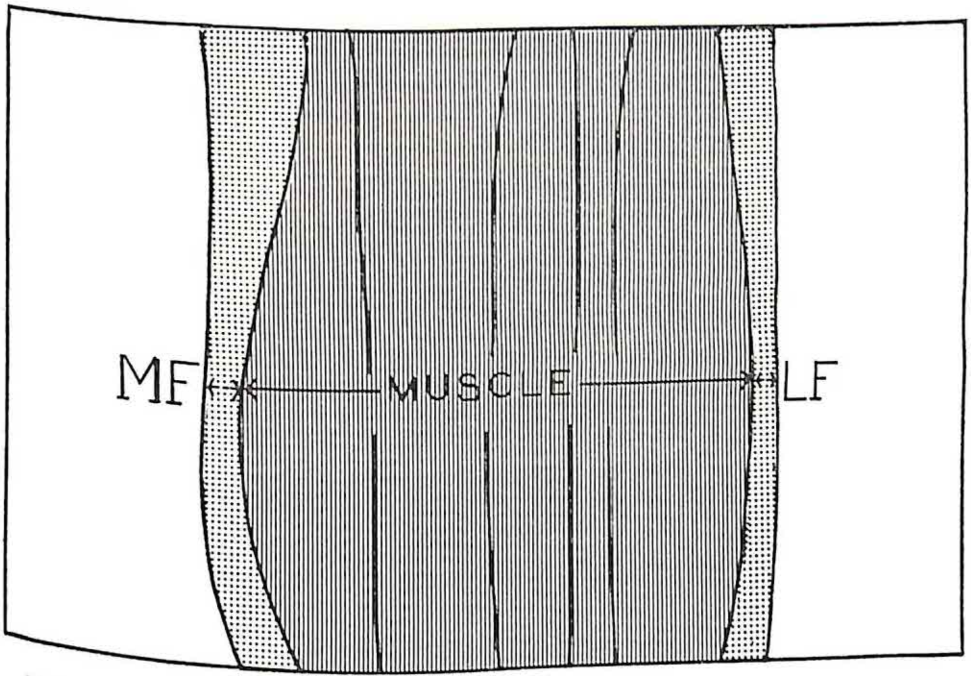


FIG. 1. TRACING OF AN ANTERO-POSTERIOR X-RAY OF THE LEFT LEG SHOWING THE DIAMETERS MEASURED. MF DENOTES MEDIAL FAT, LF REFERS TO LATERAL FAT, AND MUSCLE IS MEASURED AS SHOWN.

FINDINGS

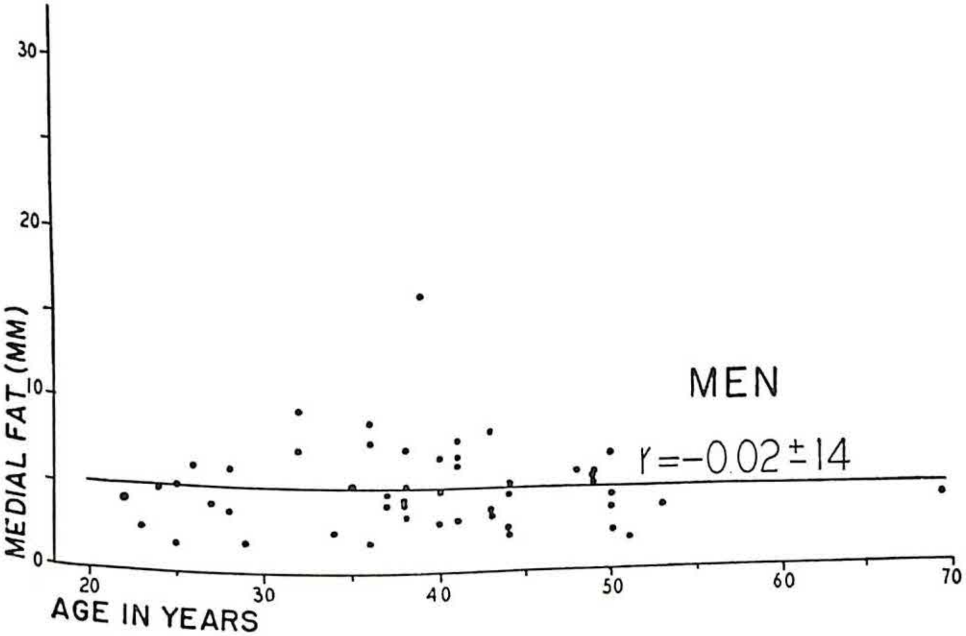
The investigation of sex differences in lower leg tissue composition was begun by comparing the diameters for men and women respectively. As shown in columns 1–3 of table 1, the *total tissue diameters* (muscle plus fat) were comparable in the two sexes and not significantly different. However, in tissue composition there was a marked sex difference. Muscle thickness averaged 107.5 mm in the men, and only 95.6 mm in the women. Fat, on the other hand, was consistently thicker in the women, with the total averaging 19.0 mm, exactly twice the male total of 9.5 mm. Percentagewise the sex differences in fat thickness were of a comparable order. Leg fat equaled 16.4% of the total tissue diameter in the women, and only 8.1% in the men.

The sexes differed not only in the amount of muscle, and in the uniformly greater fat thickness in the women, but also in the placement of leg fat. In the men medial and lateral leg fat deposits were of comparable magnitude, being 5.1 and 4.4 mm thick respectively. In the women, however, medial and lateral leg fat thicknesses averaged 11.3 and 7.7 mm respectively. The female tendency to accumulate fat on the inner margin of the leg was best demonstrated by the difference between medial and lateral leg fat. In the men the *difference* (medial minus lateral fat) averaged 0.7 ± 0.3 mm. In the women, however, the mean difference between the two layers was 3.5 ± 0.5 mm.

Since the women were absolutely fatter-legged, it was important to determine whether this difference between medial and lateral fat was a true sex characteristic, or merely a function of the amount of fat present. Accordingly 25 women and 25 men were matched for lateral leg fat, using a "matched-pair" technique (Peters and Van Voorhis, '40). Though almost perfectly matched for lateral leg fat, the women still exceeded the males in medial fat by 40%. It was thus apparent that the tendency to deposit fat differentially on the medial aspect of the leg is a female characteristic, present in slender-legged and fat-legged women alike, and not simply a manifestation of greater leg fat.

The analysis of age changes was made by comparing decade groups, by comparing subjects below and above the relevant age means, and by the use of the product moment correlation. Since the decade groups add nothing to the findings they will not be mentioned here. In the men the younger group of 25 (mean age 32) did not differ from the older group (mean age 46) in either fat or muscle (table 1, columns 4–6). No definite, and certainly no significant age changes were thus revealed. The women similarly showed no age change in muscle, but did show a marked change in fat (table 1, columns 7–9). The fat increase from the younger to the older group averaged 4.1 mm. This was due primarily to an increase in medial fat (+ 3.5 mm) and less to the insignificant change in lateral leg fat (+ 0.6 mm). Thus over two decades the women exaggerated the typically female pattern of leg fat distribution, by adding fat disproportionately on the medial aspect of the leg.

The sexual differentiation in the age changes in leg composition is best demonstrated by the correlation coefficients. In the men medial leg fat is insignificantly correlated with age (— 0.018 ±0.14). The regression line is nearly horizontal (fig. 2). In the women, on the other hand, the correlation is moderate (+ 0.43 ± 0.12) and significant at better



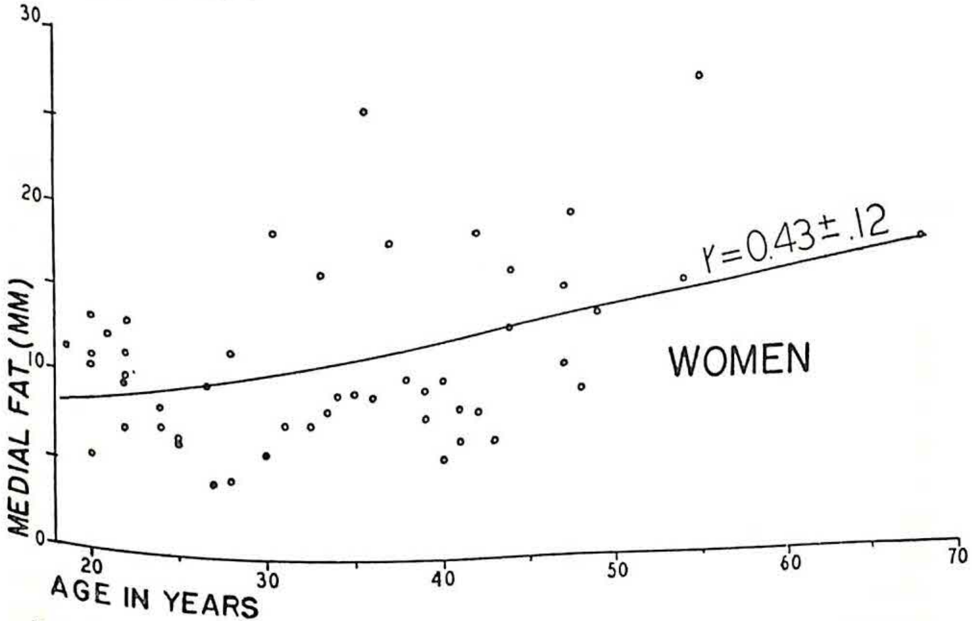


FIG. 1. SCATTERGRAMS SHOWING THE RELATIONSHIP BETWEEN AGE IN YEARS AND MEDIAL LEG FAT IN MILLIMETERS IN MEN (ABOVE) AND WOMEN (BELOW). THE REGRESSION LINES WERE CALCULATED BY THE LEAST SQUARES METHOD (Peters and Van Voorhis '40, p. 429).

than the 1% level of confidence (fig. 2). The *difference*, medial minus lateral leg fat, increases with age in women, but not in men. In men the correlation coefficient is — 0.02 ± 0.14. In women it is + 0.50 ± 0.11. There is little doubt that there is an age-associated increase in leg fat, in the women but not in the men.

Thus sexual dimorphism is evidenced in the amount of leg fat, in the placement of leg fat, and in the rate at which leg fat accumulates with age. In the age span considered fat does not accumulate on the male leg. In the women, on the other hand, leg fat accumulates at the rate of 2 mm per decade, primarily on the medial aspect of the leg. Unfortunately our data do not include subjects from the later decades of life. Therefore the age at which leg fat ceases to accumulate in the women and begins to diminish in both sexes can not now be ascertained.

DISCUSSION

The findings in this study show, as Reynolds and Grote ('48) and Reynolds ('51) have previously demonstrated, a marked sex dimorphism in the soft tissue composition of the adult leg. Though only slightly smaller in absolute diameter (— 2.4 mm), the women have far less muscle (— 11.6 mm) and far more fat (+ 9.5 mm). Percentage-wise, as well as in absolute measurements, total leg fat in these women is double that for the men. These findings again indicate the importance of considering body composition in making anthropometric comparisons. The sex difference in leg circumferences in this age group is very small, but if we consider tissue composition rather than girths, the actual degree of dimorphism is large indeed. One might also point out the errors inherent in the customary technique of relating basal oxygen consumption to surface alone, without considering what is under the surface, and its metabolic requirements.

However, totalling of fat measurements, and relating total fat to leg size and other diameters misses the most important distinction between the sexes, namely the location of the fat. In the men, fat deposits on the medial and lateral aspects of the leg are nearly equivalent. In women, on the other hand, there is a disproportionate accumulation of fat on the medial aspect of the leg. This female characteristic holds even when the total amount of fat is considered. It is obviously important, in studies of body composition, to determine where the fat is located, as well as how much fat there is. Moreover, recognizing this differential pattern of fat accumulation, one senses a further explanation for the apparently higher incidence of *genu valgum* ("knock-knees") in women. And one sees why the sexes differ in the contour of the "inner calf curve," at least in the age span considered here.

The age changes observed in this study deserve especial comment because they are not what we expected to find. Following Keys ('53), and Brožek and Keys ('50 and '51), as well as other studies using the Behnke technique, we expected an age-associated loss in muscle and a gain in fat in both sexes. In our men there was no significant change in either muscle or fat as age progressed. In the women, while muscle remained constant, there was a notable age increase in fat, especially in medial leg fat. Thus the female characteristic, a high ratio of medial to lateral leg fat, becomes even more pronounced in later years.

These findings in no way contradict those obtained by other techniques. Fat need not accumulate upon the calf of the leg to the extent that it does on other parts of the body. A shift in specific gravity merely means that fat has been added or muscle lost, without telling where the loss or gain has occurred. The roentgenographic and the densitometric techniques supplement each other in telling us how much and where soft tissue has been gained or lost. However, it is notable that during the age range considered the male leg remains seemingly constant in composition. Evidently the decreasing output of testicular hormones does not result in a parallel loss of leg muscle. In the aging female, on the other hand, muscle size remains constant, but the leg rapidly accumulates fat.

There is no immediate explanation for this sex difference in fat distribution or in fat gain, any more than there is an immediate explanation for the relatively higher fat content of females at all ages (Reynolds '51). It is true that the woman may have an easy access to foodstuffs during the day, and it is possible but often improbable that her actual activity level is less. Yet we should not neglect the fact that oestrogenic hormones do not possess the specific metabolic effects of androgenic hormones, and during the steroid phase of development the fat gain characteristic of the female is especially pronounced.

Finally, the subject of obesity itself should be broached. In general, fat and life span are inversely associated. But the woman is at all age levels more obese (that is, fatter), and as we have seen accumulates fat more rapidly during "middle age." Yet life expectancy continues to be greater for the woman despite her opulent fat reserves. As we progress further into the investigation of adult sex differences and age changes in body composition we may find out why this is so.

SUMMARY

1. Sex differences and age changes in the soft tissue composition of the lower leg were investigated by measuring anteroposterior leg X-rays of 50 women and 50 men, largely in the 20–50 age span.
2. Though of comparable total diameter, female legs differed from male legs in their lower absolute muscle content, in their higher absolute fat content, and their higher percentage of fat (16.5% in women, 8.1% in men).
3. The sexes differed also in the distribution of fat on the lateral and medial aspects of the leg. In men the two thicknesses were comparable (4.4 and 5.1 mm respectively). In women medial fat (11.3 mm) exceeded lateral fat (7.7 mm). Medial fat was 150% of lateral fat in women and 110% in men.
4. Age changes in leg composition were insignificant in the men; the correlation between age and medial fat was — 0.018 ± 0.14.
5. In women, though muscle held constant, fat increased markedly with age, especially medial leg fat, with a correlation coefficient of + 0.43 ± 0.12 between age and medial fat.
6. Attention was directed to the necessity of investigating the location and distribution of fat, in addition to overall estimates of fat and muscle content.
7. Explanations for these sex differences were considered, and attention was directed toward the paradoxical situation where greater obesity in the female is not associated with increased morbidity as might be expected.

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DERMATOGLYPHICS OF EGYPTIANS

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THE investigation reported herewith was undertaken with two objectives in mind: first, to learn how the frequencies of finger-tip and palm patterns and of palmar main line formulae of Egyptians compare with those of other populations throughout the world and, secondly, to determine whether or not Egyptian Muslims and Copts differ with respect to dermatoglyphics. Hand prints of 271 male Egyptian students were collected at Fouad I University in Cairo, and at Assiut College in Assiut, upper Egypt. Data on the incidence of finger-tip patterns among 300 females and 1,000 males, irrespective of religion, and also of 1,000 Coptic males were obtained from government records on file at the Egyptian Ministry of the Interior. The prints of all civil employees, as well as those of house servants, are recorded in chronological order. Males and females are recorded in separate series. Our data were taken from books of records selected at random. The first 1,000 men recorded in one book, and the first three hundred women in another book, and a hundred Copts from still another book provided our information on the frequencies of patterns on finger-tips. Only those individuals having legible prints of all areas are included. Copts constitute only a small minority of those whose prints are on record. As religion is not specified on the government records, the Copts were identified by name.

Grateful acknowledgment is due to Dr. Mohammed Zaky of the Ministry of the Interior; Dr. Skellei, President of Assiut College; and Prof. F. G. Zakl, Faculty of Science of Fouad I University, without whose sincere cooperation the project could not have been completed.

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FINGER-TIP PATTERNS

Table 1 shows the frequencies of whorls, loops, and arches among each of the groups investigated. All groups are characterized by relatively high frequencies of whorls, and rather low frequencies of arches.

TABLE 1

Observed percentage frequencies of finger-tip patterns among Egyptians

SOURCE	NUMBER	SEX		WHORLS	LOOPS	ARCHES
Government files Religion unclassified	300	Female	Right	36.2%	61.2%	2.6%
			Left	35.4	58.8	5.8
			Total	35.8	59.8	4.4
Government files Muslims	1,000	Male	Right	42.5	54.8	2.7
			Left	39.3	57.0	3.7
			Total	40.9	55.9	3.2
Government files Copts	100	Male	Right	43.5	54.9	1.6
			Left	37.6	59.2	3.2
			Total	40.5	57.1	2.4
Muslims Cairo	77	Male	Right	48.0	46.1	5.9
			Left	46.2	46.3	7.5
			Total	47.1	46.2	6.7
Muslims Assiut	20	Male	Right	48.0	51.0	1.0
			Left	46.0	53.0	1.0
			Total	47.0	52.0	1.0
Copts Cairo	61	Male	Right	48.2	49.6	2.2
			Left	49.8	47.5	2.7
			Total	49.0	48.5	2.5
Copts Assiut	113	Male	Right	43.9	53.0	3.1
			Left	43.1	53.6	3.3
			Total	43.5	53.3	3.2

Among males the average frequencies of whorls ranges from approximately 40% to 49%, all four student groups having higher frequencies than those obtained from the government files. Females show the lowest frequencies of whorls, as is usually true. Consistent bimanual differences are apparent in the higher frequencies of whorls on right fingers, and of arches on left fingers. All 4 student groups show rather remarkable similarities in the frequencies of the three types of patterns.

PALM PATTERNS AND MAIN LINE FORMULAE

All 4 student populations show essentially similar frequencies of palm patterns. They are characterized by relatively high pattern frequencies in the hypothenar area and low frequencies in the thenar/first, second and fourth interdigital areas. The frequencies are similar to those observed among Rwala Arabs (Shanklin and Cummins, '37) and Syrians (Cummins and Shanklin, '37).

TABLE 2

Observed percentage frequencies of palmar patterns among Egyptian males

SOURCE	NUMBER		HYPO-THENAR	THENAR/ FIRST INTER-DIGITAL	SECOND INTER-DIGITAL	THIRD INTER-DIGITAL	FOURTH INTER-DIGITAL
Muslims Cairo	77	Right	33.7%	11.6%	12.9%	50.6%	44.1%
		Left	42.8	12.9	7.7	38.4	53.2
		Total	38.2	12.3	10.3	44.6	48.6
Muslims Assiut	20	Right	30.0	5.0	15.0	40.0	65.0
		Left	40.0	10.0	0.0	15.0	70.0
		Total	35.0	7.5	7.5	27.5	67.5
Copts Cairo	61	Right	50.8	4.9	6.5	44.2	36.0
		Left	36.0	16.3	0.0	26.2	59.0
		Total	43.4	10.6	3.2	35.2	47.5
Copts Assiut	113	Right	32.7	2.6	9.7	51.3	44.3
		Left	38.0	15.0	2.6	26.5	48.6
		Total	35.3	9.2	6.2	38.9	46.4

Main line formula 11.9.7. is most abundant, and 7.5.5. occurs relatively infrequently. Here, again, no real differences are indicated between the student populations. All are characterized by marked transversality of main lines, in which respect they resemble Europeans and peoples of the Middle East.

DISCUSSION

Caucasions manifest considerable variability in regard to pattern intensities on finger-tips. With respect to whorls, northern Europeans show 25-30% whorls, southern Europeans show 35-40% and Jews and Middle Eastern people have 35-45%. (Cummins and Midlo, '43.)

TABLE 3

Observed percentage frequencies of various main line formulae among Egyptian males

SOURCE	NUMBER		11.9.7.	9.7.5.	7.5.5.	OTHERS
Muslims	77	Right	37.6%	11.6%	10.3%	40.5%
Cairo		Left	14.2	12.9	11.6	61.3
Muslims	20	Right	30.0	15.0	15.0	40.0
Assiut		Left	00.0	10.0	30.0	60.0
Copts	61	Right	31.1	16.3	6.5	46.1
Cairo		Left	11.4	18.0	8.2	62.4
Copts	113	Right	35.4	7.9	10.6	46.1
Assiut		Left	12.3	13.2	9.7	64.8

Available evidence indicates that Caucasions are characterized by relative uniformity with respect to palm patterns and main line configurations. The hand-prints of Egyptians are typically Caucasion, and the pattern intensities on finger-tips are strikingly similar to those of other Middle Eastern people.

No real differences are indicated between the dermatoglyphics of Muslims and Copts, or between those of upper (Assiut) and lower (Cairo) Egyptians. Abdoosh and El-Dewi ('49) and Boyd ('51) have compared the ABO blood group frequencies among Muslims and Copts, and although certain differences were suggested, none were great enough to be very significant. Boyd ('51) also compared the M and N blood types, eye color, and taste reaction to phenyl-thio-carbamide, and no consistent and significant differences were apparent. It seems reasonable to assume that Egyptian Muslims and Copts are of essentially the same ethnic stock.

SUMMARY

Analysis and comparison of the fingerprints of 1673 Egyptians, as well as the palm prints of 273 of them, reveal close similarities to the dermatoglyphics of other Caucasians, especially those of the Middle East. No real differences were indicated between the dermatoglyphics of Muslims and Copts, or between those of the inhabitants of upper and lower Egypt.

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THIGH GIRTH AND NUTRITIONAL STATUS: A COMMENT

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THE paper by Škerlj ('53) reflects the physical anthropologist's growing interest in nutritional status. This interest will slowly but surely create a favorable cultural " climate " and methodology needed for a more precise and biologically more meaningful description of human physique (cf. Brožek, '53).

Because of the fundamental importance of this task for physical anthropology and for the wider field of human biology, the need for a clarity of thought and accuracy of interpretation can hardly be overemphasized. Thigh girth is a complex datum, including all 3 principal anatomical body components—bone, muscle, and fat—which can contribute varying amounts to the total in different individuals. Thus it may be confusing to say that subjects who deviate 2 standard deviations below the mean value of thigh girth are " lean," those who exceed the same positive deviation, " fat." Leanness-fatness continuum refers to the fat content. You can have a *large* but *lean* steak (or thigh). While it is true that, on the whole, a larger thigh will mean a thigh with a larger amount of intramuscular and subcutaneous fat, this will not apply in individual cases in which the muscle tissues may be the dominant factor, with a minimum of subcutaneous fat.

The information yielded by the thigh girth measurement would be markedly improved by the addition of a skinfold measure (at the same height, on the frontal surface) and perhaps also of the width of the femoral condyle, as an index (together with stature) of the skeletal mass. While it is true that adequately standardized calipers and methods of measurement had not been available, for many purposes this does not invalidate the use of home-made calipers, "standardized" by and for the particular investigator. The question of standardization becomes crucial for inter-laboratory comparisons and for setting up generally valid norms.

While the correlation coefficients calculated by Dr. Škerlj are of interest in their own right, as descriptive statistics, few of the data are relevant to the topic of nutritional status. The high correlation of thigh girth with weight would indicate that, under conditions of normal body hydration (absence of edema), the use of the thigh circumference would add little to the information about the caloric aspects of nutritional status provided by relative body weight (actual weight as percentage of the sex-age-height standard). The correlation of the latter characteristic with the classification according to the "plastic" type is not given.

The use of an anthroposcopically assessed charcteristic, such as the plastic type, as a criterion against which the anthropometric data are validated is a basically questionable procedure. Yet this is the only procedure used in the study.

TABLE I

Circumferences, in cm, measured in 32 young men during the control period (C) *and after 24 weeks of maintenance on a highly reduced caloric intake* (S24). $\Delta = C - S24$. $\Delta\% = 100\Delta/C$. SD_c *= standard deviation of the distribution during the control period, used as a measure of "deviation from normal."*

Circumference	C	$S24$	Δ	$\Delta\%$	Δ/SD_c
Thorax	89.3	82.6	6.7	7.5	2.0
Abdomen	78.1	70.7	7.4	9.4	1.7
Upper arm	28.5	21.5	7.0	24.5	3.9
Thigh	47.1	38.0	9.1	19.4	3.2
Calf	37.7	33.0	4.7	12.5	2.8

A more rigorous approach is to examine the differences in anthropometric dimensions (circumferences) in groups of individuals whose nutritional status is known to have changed drastically. The data for 5 circumferences, measured in the Minnesota starvation-rehabilitation experiment (Keys, et al., '50) are presented in Table I. The decrement in thigh girth, whether expressed as percentage of control value or, preferably, in terms of the displacement ratio, is exceeded by the upper arm. The reason for the differences between the limb circumferences has not been definitely established. Th principal factor is likly to have been the initial amount of subcutaneous fat. The second factor could be edema. Perhaps edema affected the calf most, the arm least. This would be a definite reason for using the latter in preference to measurements on the lower extremity. It may be noted, in passing, that in Howells' ('52) factor analysis of body build it was also the *upper arm* circumference which had the highest positive score on the first (endomorphy-ectomorphy) factor.

TABLE II

Crossectional areas of the limbs, in cm². For legend see Table I.

Crossectional area	*C*	*S24*	Δ	Δ%
Upper arm	64.6	36.8	27.8	43.0
Thigh	176.7	114.6	62.1	35.0
Calf	113.3	86.8	26.5	23.4

The changes are more impressive when we deal with crossectional areas rather than with the linear circumferences. These data are included in Table II. To be more precise, one should correct both the control (C) and the starvation (S24) values for the crossectional area of the bone, estimated from roentgenograms. For thigh, the values of the corrected crossectional area (area of soft tissues) were $C = 170.6$ cm², $S24 = 108.5$, $\Delta = 62.1$, $\Delta\% = 36.4$. Ideally, the values for the crossectional areas of subcutaneous fat and muscle should be evaluated separately.

There are two methodological limitations noted in Dr. Škerlj's communication which can be easily remedied. Rather than working in an area very close to the sex organs, the circumference could be readily measured at the mid-thigh level (midway between the top of the patella and inguinal fold). With the subjects sitting, this point can be determined and duplicated with considerable precision. Variations in pressure can be obviated by the use of a constant pressure tape.

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HUMAN BIOLOGY
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POPULATION AS THE UNIT OF STUDY IN HUMAN BIOLOGY

Chiefly by chance and only slightly by design, the editors find virtually a whole issue of *Human Biology* devoted to demographic studies. But should one call it chance when a series of unrelated papers, although on widely divergent subjects, turn up at one time on the editor's desk with a common theme? Instead, it may signalize a meaningful current emphasis on the relation between human biology and demography. One of the articles is by a sociologist and a demographer who found it important to start with a census of the Hutterites in order to measure their mental public health. The census revealed an unusually high fertility and a population that, without immigration, increases itself at a much greater rate than any previously studied. A second article is by an applied anthropologist who finds population characteristics important in respect to human ecology. In this study of an American Indian village, vital statistics are viewed in the light of the cultural and physical environment of the group. The third is a brief attempt at the reconstruction of demographic characteristics of historic peoples from such literary sources as the Bible. The fourth article is by an ethnologist. He presents data on intertribal mating of Australian aborigines at the time of first contact with Europeans. This study of a stone-age people will permit estimation of one of the variables—the rate of intermixture—which physical anthropologists use in calculations based on the genetic theory of the evolution of human races. When we apply this theory to the question of human evolution, the high rates of intergroup mating which are here reported for the Australian aborigines lend weight to the argument that in man there must always have been a considerable tendency towards race amalgamation.

Population, then, is the unit of study in some modern approaches to the evolution, genetics, and ecology of man. It should be one of the central themes of our journal. As one correspondent commented, "There are an increasing number of research problems in which biologists and demographers are looking at the same phenomena, sometimes the same data, with related but somewhat different goals and quite different analytic procedures."

Human Biology, of course, is not to be limited to demography any more than to physical anthropology, biostatistics, or any other single aspect of the field. In the future we may wish to emphasize—perhaps again with a group of articles—the relevance of human biology to some other discipline, nutrition, for example, or immunology. However, in maintaining our independence of any one professional group, *Human Biology* risks the loss of the support which such affiliation can give. The convergence of interests of human biologists and demographers should have two facets. On the one hand, more readers of *Human Biology* may wish to join the Population Association of America * and thereby identify themselves with others who have a serious interest in the scientific study of population. On the other hand, demographers can increasingly support *Human Biology* through contributing articles and through subscribing.

GABRIEL LASKER

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* Population Association of America, c/o National Office of Vital Statistics, Department of Health Education and Welfare, Washington 25, D. C. Secretary: Hugh Carter. Dues: $3.00. Members receive the Population Index and other publications.

MILK "LET-DOWN" AND THE ORGASM IN THE HUMAN FEMALE

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THE nature of the phenomenon of milk let-down in the cow has been investigated by one of us (Petersen '44) and has been demonstrated to be a result of release in the blood stream of the oxytocic principle. This has been shown to be induced, under ordinary conditions, reflexly by sensory stimulation of the udder. The 45 seconds usually intervening between the application of the cutaneous stimulation to the teats and udder and the response in the parenchyma of the gland in the lactating cow is sufficient for and consistent with a reflex phenomenon having a neural afferent leg and a hormonal efferent leg of the arc. The phenomenon is of similar nature in the human female, as many published observations as well as those of the present authors indicate. Both sensory and psychic stimuli serve to evoke the milk let-down in the lactating female and the observation of the phenomenon is commonplace though frequently subjective in the woman herself. Where much milk is present, or the nipple sphincters are faulty, it may be observed by others as a running of milk from one breast as the infant is put to the other. The clinical importance of this phenomenon in the instance of its failure in lactational non-performance in women has been commented upon in an earlier publication (*loc. cit.*) and by Newton and Newton ('50).

The purpose of the present communication is to report a series of observations which lead the authors to the view that an extension of the phenomenon of milk let-down is to be observed in lactating females subject to sexual stimulation, and to examine the implications of these data in relation to the biology of the female orgasm.

Despite the wealth of literature, recent and early, dealing with the female sexual response, considerable confusion exists as to its real nature and place in the economy of the individual. Some authors consider the female orgasm as exact a homologue of the male phenomenon as the anatomy of the parts will allow. Others consider the essential response to be a completely subjective one, i. e. psychic, and not observable to others but only to be inferred (Ford and Beach, '51, p. 252). As to its place in bodily economy, opinions vary from the view that it is of no importance to the reproductive act to the possibility that it is facilitatory if not essential to the sequence of events leading to fertilization. It is believed that the following observations may explain some of the confusion which has beclouded this subject and, perhaps, lead to a more productive hypothesis by which sexual responses may be studied.

Five human cases in which milk let-down in the human female has been correlated with sexual responses have been studied. Each has been observed by a physician or a scientist. The one for which there are the most observations is a multiparous woman, who observed with each of her 4 lactating periods that the sexual act usually resulted in a copious flow of milk. This might not have been observed so clearly, or possibly not at all, if it were not for the fact that the nipple of her left breast was somewhat inadequately supplied with a sphincter. In this subject, the milk let-down at nursing was more observable than usual and could be seen to result from the anticipation of putting the baby to the breast. Thus, in this instance, cutaneous stimulation was not essential.

The other four cases were essentially similar but have not been studied with the same thoroughness of the instance reported above. An important agreement between the cases is that in regard to the let-down of milk during sexual intercourse, there was observed a correlation between the fullness of the sexual response and the let-down phenomenon, it being much more marked when the woman felt a greater sexual response had been achieved.

Additional observations of this phenomenon have been made in cows. Cannulation of the teat canal has not been employed but observation of the let-down phenomenon has been made by virtue of the sudden turgidity of the lower portion of the udder and teats or by dripping of milk. Two instances in which the let-down was seen during copulation are reported. Another, equally interesting case, in which a veterinarian provoked a milk let-down by the manipulations involved in making a rectal palpation of the uterus is considered by us to be significant. Reference should be made to the detailed and similar observations reported by Van Demark and Hays ('52).

The significance of these phenomena seems to us to be that they offer support to the hypothesis that in human sexual behavior—as well as that of the cow and certain other mammalian species—the female copulatory response is essentially a double entity. There appears to be an essential component, of the nature of a neuro-humoral reflex, involving the oxytocic principle of the posterior hypophysis and possibly—in view of the well known ovulatory response to coition in rabbits and other species—hormones of the anterior lobe of that gland (Figure 1). This results from the stimulus of erogenic zones and also psychic influences with activation of visceral effectors through the hormone system. The biologically essential features of female reproduction—oestrus, sperm transport, ovulation, and lactation are integrated in this way—apparently in a single sequence of events in certain species. What is popularly known as the female orgasm may in whole or in part be represented by a vestigial male behavior pattern, with a fundamentally different organization. The essential responses of the male orgasm consist of erection

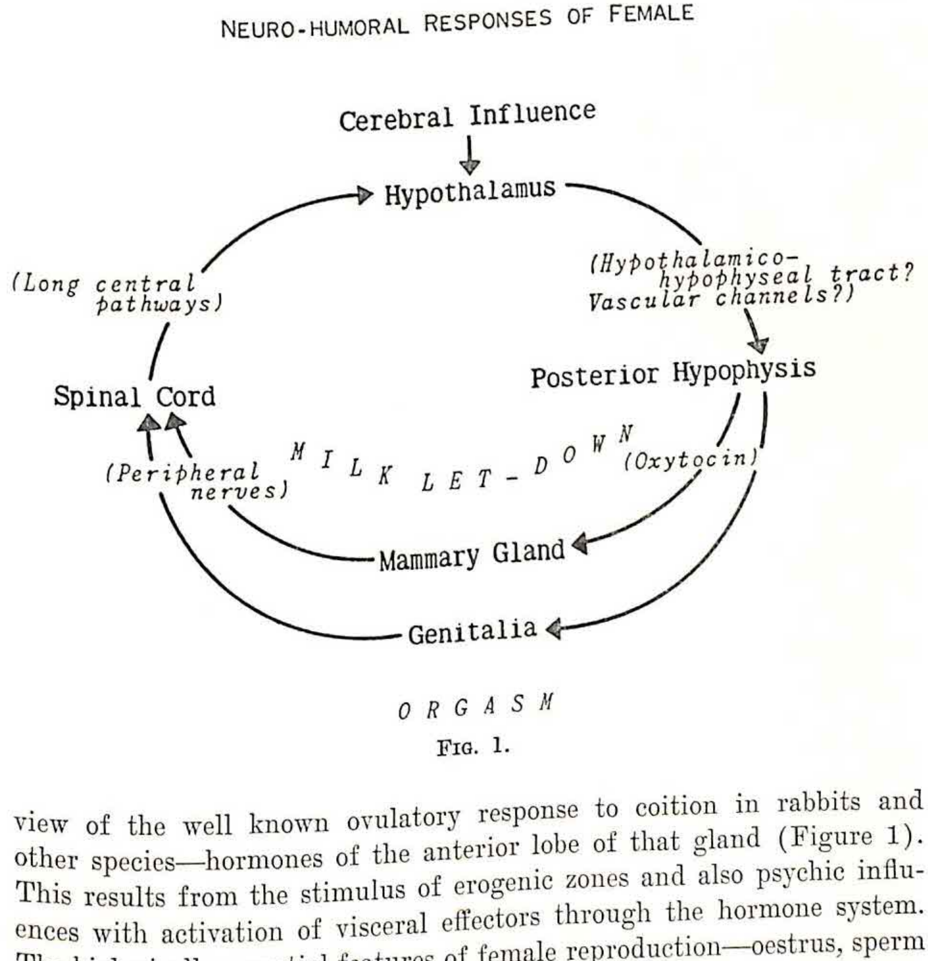

FIG. 1.

of the genitalia, the copulatory act, and a burst of motor activity of the musculature of the genitalia at ejaculation. That the male pattern is resident as a separate entity in the behavioral organization of the female mammal has been shown and discussed by Beach ('38). Such behavior is commonly observed in domestic animals. That it is scarcely to be found in the infrahuman primates (Ford and Beach, '51) is a matter of interest to which we will later return. The immediate point of the discussion is that not only is the motor activity associated with orgasmic behavior in the human female a somewhat variable series of contractions of vestigial and functionless homologues of the musculature of the male genitalia, but there seems to be a consensus that such a response depends greatly upon stimulation of the clitoral homologue of the penis.

The acceptance of the view that the human female orgasm is a double behavioral entity consisting of an essential neurohormonal reaction of smooth muscle organs not represented in the male and a usually concurrent vestige of a male behavior pattern typified by contraction of the homologues of the muscles of ejaculation would have certain interesting and clarifying consequences. The lack of strong correlation between fertility and orgasm as usually defined not only in women but in domestic animals subject to artificial breeding would be understandable in view of the fact that it is the vestigial and non-essential male behavior with which the correlation is attempted. The real female orgasm, as detected by milk let-down or by blood hormone levels, may well have a high correlation with the success of the reproductive act. It would aid in explaining one of the more surprising findings of reproductive behavior of the infrahuman primates, where any visible sign of a female orgasm (as usually defined) is absent (Ford and Beach, '51). Such a view would have implications in the fields of sociology and mental health which would need exploration.

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TRIBAL AND INTERTRIBAL MARRIAGE AMONG THE AUSTRALIAN ABORIGINES

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INTRODUCTION

THIS paper brings together field data on the ratios of tribal to intertribal marriages among Australian tribes whose cultures have not been grossly disturbed by the effects of European contacts. Such data had hitherto not been gleaned for the Australian aboriginal. It may be important as background information for those interested in many different aspects of the study of human gentics. Along with data now being collated, as to interval between generations, it may serve to indicate the likely general rates of transmission of genes from one group to another among primitive peoples at the cultural levels of Australian hunting peoples.

The researches on which the paper is based were made possible by grants for field work from the South Australian Government, the Carnegie Corporation of New York, the Wenner-Gren Foundation, the University of Adelaide and the South Australian Museum.

The material was brought into focus and tested by reexamination of methods etc., after the 16th Expedition of the Board for Anthropological Research, University of Adelaide, which visited Yuendumu, Central Australia in August 1951.

The paper is offered in its present form at the request of my colleague Dr. J. B. Birdsell, who was a fellow worker on one of the principal expeditions, when about one-half of the data for it was gathered.

All the genealogical data on which it is based were recorded by the present writer, and have been checked with official data where such exist. The raw material is preserved on a series of record cards and in seven large folio manuscript volumes of genealogies which are lodged for permanent preservation in the South Australian Museum by the Board for Anthropological Research at the University of Adelaide.

The territories and names of tribes referred to, with one exception, the Wenamba, discussed herein, are shown on the map published by Tindale ('40).

This map in general gives an appreciation of tribal territories at the time of early white contacts and is approximately accurate only as reflecting conditions at a given moment of time just before disruption by European intereference.

RANGE OF MOVEMENTS OF AUSTRALIAN ABORIGINES

Epipalaeolithic hunter-tribesmen, as typified by the Australian aboriginal, were nomadic within a tribal area, and were closely tied to this territory by the continuous necessity of gathering the day's food and spending the greater part of each day doing so, leaving little time for other activities, save at a few especially favorable seasons of the year. They had limited means of travel and, should they wish to move from their living area, faced ecological barriers and physical obstructions as well as hostile opposition from armed owners of adjoining tribal territories. They suffered also psychological fears if they came to trespass on unknown territories, and when confronted with new foods they had not previously encountered. Despite their continual wanderings they were not widely travelled.

Study of tribal habits suggests that transmission of human genes across Australian territory probably has taken place in several ways, of which the following are significant: (a) by migratory movements either of tribes, of hordes or of families. (b) by intermarriages followed by movements of individual husbands or wives of one group to the territory of the other, (c) rather more rarely by the movements either of couples who have transgressed marriage laws in one tribe or who have made intertribal marriages against others wishes and then shifted elsewhere, sometimes as refugees from tribal justice, and (d) sanctioned sexual license across tribal boundaries where tribes meet for ceremonies. In exceptional cases casual choice or unusual opportunity has determined the transgression of a tribal boundary.

The main modes of possible migration of genes are discussed below in more detail.

TRIBAL MOVEMENTS

In the past mass tribal movements probably have occurred in Australia and some actually were occurring at the time of early contacts with Europeans. Some of the known early movements have a southward component, a few were in the diametrically opposite direction.

The Pintubi tribe studied in this paper, in common with the Pitjandjara and Jumu, have made considerable south-eastward movements, of the order of 50 to 100 miles during the past several generations; their latest shifts were initiated in 1916, after a severe drought had forced them to travel away from their usual territory. The Pitjandjara, for example, in usurping the present eastern half of their country, ambushed and killed many Jangkundjara. About one-half of the surviving Jangkundjara shifted their living area to the vicinity of Ooldea to escape the Pitjandjara. Present day Pitjandjara totemic places are all west of the Musgrave Ranges, although one-half of the modern territory of the people is about that Range, and once all of it lay beyond their eastern boundary. The Jangkundjara people whom they displaced had previously occupied the same territory for at least several generations.

There is evidence that the Kokata and Pangkala tribes further south had shown similar south-easterly movements during a period of over half a century, prior to 1914. How far these movements either were intermittent, continuous, or even at times reversed is not known.

The forces determining migration are not easy to ascertain, but the highly variable rainfall of the desert regions is an obvious cause, and high population pressure is evident also as a factor since in a long run of good seasons many children are born in the desert areas.

The afore mentioned Pitjandjara movements do not seem to have been caused by any decline in numbers, and hence of prestige and power of resistance, of tribes-people who opposed them on the east. It is true that the eastern tribes, including the Kukatja, Jumu and Jangkundjara have been on the outer fringes of white occupation since the turn of the century, and therefore might be thought to have weakened. However the movements south-eastward seem to have been initiated before any disturbance patently due to white influence.

Later day movements, due primarily to Post-European releases of population pressure caused by the dying out of tribes living near to areas of white settlement, are well known and are to be distinguished from these earlier movements. Thus with the virtual disappearance of the civilised Wirangu tribespeople on the West Coast of South Australia after 1910, the inland Kokata came to the coast about 1920, and now tend to regard it as their territory, even though they remember the desert to the North as their former home. They also have come to regard Port Augusta, once in Pangkala territory, as now in their country, for the Pangkala have all died out in contact with whites.

Although it seems to us that the earlier movements were " natural " it is of course difficult to assess what might have been the nature of the tribal dislocations and disturbances due to events such as the smallpox epidemic which swept across Australia from coast to coast in the 1830's and in some areas greatly reduced the population. This smallpox epidemic probably was introduced by the Malays who then frequented the northern coasts of Australia. These Malays perhaps had done so for centuries. In this event it might be thought to be a " natural " or a " Non-European " effect on the Australian population.

Studies in the material cultures, languages, and traditions suggest that in Central Australia a slow southward drift has been going on over an extensive period of time, but other movements show a northward trend from the MacDonnell Ranges in the direction of the Tanami plain. In the cases of the Pitjandjara, Jumu, Pintubi and similar tribes the reality of the movements is reflected in their totemic beliefs and ceremonies, for many of their rites and stories have their settings in places up to 100 miles west of their present places of living. Ngalia mythological tales show a trend; a movement towards the MacDonnell Ranges from the west and then one north from near Winbaruka (Blanche Tower) to their present locations centering on Mt. Doreen.

EXTRA-TRIBAL MARRIAGES

Gene flow is possible, in the absence of tribal movements, and of direct physical contact made by native messengers, to the extent that intertribal contacts and marriages take place.

Where areas and population are comparable in size etc., extra-tribal marriage rates of the order of, say 5% will cause a much lower rate of transmission of genes than where up to say 35% of marriages may be extra-tribal.

For a group of the Ngadadjara people living in the Warburton Range, Western Australia, as observed by the present writer, in 1935, we have a record of 42 remembered marriages; yet among these people, 9 were extra-tribal marriages linking them to adjoining tribes. One of these was with a member of the Nana tribe, a neighboring group to the northwest. This marriage had taken place perhaps 15 years prior to 1935 when a Nana man had taken away a Ngadadjara woman. A meeting of these two tribes, for the first time since that event, was witnessed in the Warburton Range, August 1935, by members of the 11th Expedition of the Board for Anthropological Research, University of Adelaide. On this occasion the Nana group chanced to come from the northwest, seeking water at Warupuju, having been forced thereto by drought in their own territory. After this interval of time the woman had borne one boy child whose tribal affiliation was hybrid although he was regarded, following his father, as a Nana child. In the same Ngadadjara tribe there were 7 marriages with Pitjandjara and one with Mandjindja. On this basis just over 21% of marriages were extra-tribal.

Among about 150 Pitjandjara encountered in the Mann Range in June 1933 there was one Pintubi woman whose Pitjandjara husband had received her by an intertribal exchange marriage. (Incidentally with her he had received a suite of unwanted secret ceremonial objects for which he and his tribe had little use.)

In all but one of the above instances the woman was the one whose area of abode had been changed by the marriage and this seems to be very general in Australia where, typically, marriages are patrilocal. In the Ngalia tribe studied in detail in the next section of this paper there were several instances where the reverse was the case. Matrilocal displacement of marriages have been reported as well in other places but they tend to be less than patrilocal ones.

It is evident that among the Pitjandjara and Ngadadjara intertribal unions were not unusual events and fitted properly into their life patterns. The instances were ones which had taken place among people who had not been in close contact with Europeans at any time prior to these marriages and at the time the observations were made were still living their full life as Epipalaeolithic hunters. Indeed so completely unaffected were they, that they still were using exclusively stone implements for their daily work of spear making, dish and implement cutting, and food gathering.

The existence of intertribal marriages therefore must be accepted as normal, since people who encounter each other on the margins of tribal territories, though often nervous in each other's presence, apprehensive, and often at enmity, do engage in barter, occasionally do give women in intertribal marriage, and though they fight, and kill, either to hold their territory, or to usurp that of others, they do extend hospitality to those in need of water or temporary subsistence. Such courtesies might be thought by some to be more characteristic of western Desert Tribes, but they seem also to be present in populations less subject to arid climate vagaries. For instance among the Tanganekald of the Coorong in South Australia an elaborate system of allotting temporary living space was practiced when droughts made it necessary to share food. In the desert areas attitudes of hostility seem to be tempered by the knowledge that today's owners of food and wells of water, by tomorrow, of necessity may be waiting on the good will of others who by reason either of good fortune or successfully conducted magical rites have enticed to their land a thundercloud full of water, and so have obtained life-giving rain for their hunting area.

INTERTRIBAL MARRIAGES IN A SELECTED TRIBE—THE NGALIA

In the Yuenduma area of Central Australia the principal tribe, now to be studied, is the Ngalia, one of the so-called Walpari (Walpiri, Alpiri, Ilpira) tribes. The last named term appears to be a blanket one applied in the area north west of Alice Springs to several desert dwelling peoples speaking non-Aranda-type languages.

Ngalia territory extends from just west of Cockatoo Creek westward to the vicinity of Konadjarai (Coonajarrai of maps), south to the salt marshes which run along the south side of Stuarts Bluff Range and along its westward extension, the Jupareri Range (a native name not yet on maps). The center of their territory lies at about 131° 0′ East Longitude by 22° 10′ South Latitude. They go also to south of Mt. Stanley (Karko), to Mt. Cockburn (Winatata), and to the sandhills and the spinifex-grass-covered sand desert country north of Mts. Singleton, Doreen and Hardy. The area occupied by the tribe is approximately a rectangle, 75 by 150 miles, comprising roughly 11,000 square miles, and supporting 400 aborigines. It thus furnished living areas of between 25 and 30 square miles for each person, a relatively dense population when compared with other areas where there are up to 150 square miles per person. The country comprises a central core of mulga (*Acacia aneura*) scrub among granite ranges and a peripheral zone composed of sand plains covered with "spinifex" grass (*Triodia*).

The aborigines of this tribe probably saw such nineteenth century explorers as Warburton, who made his nineteenth camp west of Mt. Eclipse on May twelfth 1873, and Gosse who camped at Cockatoo Creek on May nineteenth 1873. Both refer to having seen clues to the existence of natives or had brief encounters with them. Although brief visits were made by other explorers (e. g. by Barclay in 1911), it was not until well after World War I that the country began to be frequented by whites prospecting for precious metals. Wolfram was located by the late Alec Ross in August 1926 at Mt. Doreen. W. W. Braitling first visited Mt. Doreen in May 1926 (and later settled there in 1932). Shortly after Braitling's first visit, a white man, Brookes, was killed by Ngalia natives (1928) and on two occasions police punitive expedition killed members of an eastern horde of Ngalia natives near Cockatoo Creek. For most of the adult Ngalia aborigines alive today their earliest recollections of Europeans were of contacts with Ross and with Braitling in 1926 or at various dates thereafter.

The Ngalia have as northern neighbors the Walmala, another of the so-called Walpari tribes, whose territory embraces the desert plain extending north west from Cockatoo Creek to the Granites and north east to Lander Creek. The chief present day home of the Walmala is at the Granites. Messrs. W. Morton and S. Sandford settled on the lower Lander Creek in May 1926 and two years later the Walmala natives made an attempt to kill the former. Their adjustment to European occupation commenced at about that date.

East of Cockatoo Creek is the territory of the Anmatjera, who speak an Aranda type language. Because of the very considerable language differences, the separation between Ngalia and Anmatjera is a marked one. The Anmatjera first clashed with whites in an attack on the newly erected Barrow Creek Telegraph Station in 1874. This event is still remembered by one (now very aged) native who was present in the vicinity as a boy. After this episode they had relatively few contacts with whites until the first period of pastoral expansion. Their territory was disrupted by the taking up of Conistan Station for cattle in 1920.

West of the Ngalia live the Wenamba or Wenanba, still (1951) not in direct or constant contact with whites, although some of them visited Ngalia territory in 1950 and a few natives, probably of this tribe or of the Kukuruba, were met during a recent reconnaissance of the little known area north of Lake Mackay by W. W. Braitling.

Much of Ngalia territory has been opened for general pastoral settlement in the past decade, and a ration depot is established at Yuendumu to provide for natives whose hunting territories have been disturbed by the advent of cattle. The period of intense disruption of tribal life is therefore short; three marriages only are ones in which native law has been broken and only a small handful of halfcastes has been born.

The authority and power of the native old men is only now beginning to weaken, as young natives, lately educated as stockmen, begin to assert themselves through their superior opportunities for contact with the Europeans whose cattle they tend.

With this background it becomes evident that it is possible to obtain interesting and significant data on marriages initiated prior to European influences and also to examine the histories of the several instances of departure from the more usual marriages within the tribe.

Original data for the group was obtained by the present writer during a visit to Cockatoo Creek in 1931 (7th Expedition of the Board for Anthropological Research, University of Adelaide), and gathering of data was repeated and amplified during the 16th Expedition, in August 1951.

Genealogies were gathered on 103 sheets. They give some data on about 163 Ngalia marriages. Records of some of the marriages appeared independently on several different genealogical sheets; some were listed first in 1931 and the same data recorded again in 1951 and for still others information, independently gathered, appeared in an official list prepared at Yuendumu Station in 1946 for a Census of natives. Hence cross checks on the data often were available. In 156 marriages for which data as to tribe was ascertained the following tribal relationships were found to exist between the marrying parties.

TABLE 1

Tribal and intertribal marriages

TYPE OF MARRIAGE	NUMBER OF INSTANCES
Ngalia man married Ngalia woman	144
" " " Pintubi woman	1 (adjoining tribe)
" " " Anmatjera woman	1 (" ")
" " " Jumu woman	1 (" ")
" " " Walmala woman	1 (" ")
" " " Aranda woman	1 (1 intervening tribe)
Ngalia woman married Walmala man	2 (adjoining tribe)
" " " Pintubi man	2 (" ")
" " " Aranda man	3 (1 intervening tribe)

From these details it appears that of those who made intertribal marriages, Ngalia men comprised 3.2% and Ngalia woman totaled 4.5%. Extra-tribal marriages therefore were of the general order of 8%. On this basis it would appear that Ngalia contacts with other tribes were relatively few. This may be accounted for by peculiarities in their geographical situation. Their best country is the Mt. Doreen area, a relatively fertile strip of granitic country with "sand soaks" in creeks and many rock hole waters. This good country is embraced in almost every direction by "spinifex" grass covered sand plains which were very unattractive as places of native residence and likely to discourage the passage of outsiders. Nevertheless it would appear that Ngalia men have taken other women in marriage and men of surrounding tribes, having obtained Ngalia women as wives have come to live permanently with their wives, therebye swelling the effective number of intertribal marriages in the Ngalia area. Of 12 intertribal marriages 8 were with members of adjoining tribes and in 4 instances with members of tribes once removed.

The three instances noted where Aranda men of a non-contiguous tribe have come into the area and married Ngalia women appear old enough to be allowed as free from direct European influences. In each instance the man concerned appears to have come to the Ngalia country relatively early in life to escape a feud, and has remained. The marriage of the Aranda woman with a Ngalia man listed above is recent, and the woman has had ties with Hermannsburg Mission. However, the marriage seems to have occurred as a direct and logical result of one of the earlier series of mixed Aranda marriages and possibly would have taken place even if the Aranda had not come under European influences. If, to be on the safe side, we disallow it the percentage figure is about 7.5% for intertribal marriages made by Ngalia people (based on the observation of a total of 155 marriages).

In addition to the simple intertribal marriages referred to above there was one instance where a "Ngalia" man, himself a product of an earlier Ngalia man X Jumu woman marriage, wedded an Anmatjera woman whom he brought to live in the territory of his father. Taking into consideration this anomalous instance the degree of tribal intermarriage is about 8%.

In compiling the above data on marriages, three recent ones known to have been directly influenced by Europeans and by rapidly increasing present day European contracts have been rejected as unsuitable for inclusion. In two of the rejected instances the subjects are trusted cattle station hands, Ngalia men with knowledge of English. This knowledge they obtained through early attachments to Europeans by whom they were taken away from Ngalia country. These two men have used their prestige to force "wrong" marriages with Ngalia girls. Further details of such "wrong" marriages are to be given in a separate paper dealing with the social organization of these people. Although Ngalia 8-class marriage rules tend to allow some *ngawuru* (mother's brother's daughter) marriages, there had not been any for some time and these particular ones which directly flouted the old men's arrangements were not very acceptable to the group. The third marriage also omitted from the lists is one bitterly opposed because, under missionary influence and through bribery (with trade goods and food to the claimed value of £10) a young Ngalia woman, promised from birth to an older man, had recently (February 1950) been married to a young man. This, the first church wedding among the Ngalia, transgressed their native law since a Tjungarai man had married a Nakamara woman, i. e., had taken to wife a person who stands in the relationship of "father's wife."

These three marriages are the main ones which have transgressed native sentiment and the consummation of one of them has been blamed for several grudge killings, including an affair of April 1951 when two natives lost their lives and about 40% of the native population left the vicinity of the Government Station and had not returned at the end of 4 months after the fracas.

Since marriages among the Ngalia are in general arranged while the girl is still in infancy, or may even be arranged prior to birth of a child, on a contingent basis, even the most recent marriages, other than these three cases, reflect the normal practice of the natives before being subject to European influences, and there can be little hesitation about their acceptance.

Data on an additional 4 marriages had to be omitted either for lack or for partial lack of tribal data.

It was very difficult to obtain information about anyone who is dead. Ngalia people seem less inclined to talk of the dead or to recall their names than any other Australian tribes-people encountered by the present author. The suppression of references to deceased ones is so complete as quickly to destroy remembrance of details of marriages etc. Hence, in this Ngalia study, data could not readily be obtained for previous generations sufficiently far back to test whether or not there might have been any changes in rates of inter-marriages with passage of time. All the data therefore has been pooled to obtain the information summarized in preceding paragraphs.

DATA FROM THE HARVARD-ADELAIDE UNIVERSITIES ANTHROPOLOGICAL EXPEDITION 1938-1939

Data on tribal and intertribal marriages of full-blooded aborigines in some degree comparable with that for the Ngalia, are contained in the genealogies of native families recorded by several earlier expeditions of the Board for Anthropological Research with which the present writer has worked, although it was not specifically gathered with the intention of recording this particular facet of native life.

During the Harvard and Adelaide Universities Anthropological Expedition 1938-1939, a very large amount of data was obtained during studies in 5 States. This Expedition worked chiefly among detribalized remnants of peoples, but information was gathered on some marriages initiated prior to disturbances due to advent of Europeans. When tabulated these have yielded some useful information.

LIMITATIONS OF THE 1938-1939 DATA

Since knowledge of exact dates for such marriages usually are absent and the actual time of first contacts is known only broadly for each area, the data are not as exact as might be desired and subjective judgments may have gone into the assessments of some borderline cases.

Cases where the woman whose marriage was being considered had borne full-blooded children (prior to having had one by a European) were usually not difficult to assess for inclusion in the data for the birth of halfcastes takes place principally in the first few years of direct contact with whites. If the circumstances indicated the marriage had indeed taken place prior to any period of systematic contact between the aboriginal group and whites, the data on the marriage were taken into account. For some areas marriages of as late dates as the 1920's and 1930's could safely be included, whereas in others (for example parts of South Queensland), marriages after about 1850 had to be excluded. For South Eastern Australia, therefore, there is not as much information as desirable and in much of New South Wales and Victoria little useful material was forthcoming.

In tabulating intertribal marriages patrilocal residence has been assumed except where there is data indicating the contrary. This may have led to a few anomalies in the setting out of the tables. As an example the details for the Idindji tribe show few intertribal marriages since few woman were imported into the tribe. However for the Mamu, Ngatjan and Gulngai tribes relatively numerous intertribal marriages with Idindji women are recorded since Idindji women did go to live among these tribes. The discrepancies may be more apparent than real. In this particular instance it is difficult to assess how far the situation might have been caused by early day clashes between the Queensland native police and Idindji coastal aborigines. In the "bad days" of the 1890's there was much killing off of male natives during Native Police raids in coastal areas not settled by whites. Surviving women may have gone inland in marriage. On other evidence it is known that intertribal marriages were common in this particular area and were sometimes due to the stealing of women from one group by another and the disparity in numbers may be due to the greater advantage held by mountain people over those confined to a sand-beach and coastal plain, as described to me by some Kongkandji men.

Intertribal marriages which are directly due to European disruption usually begin when aboriginal men, in contact with Europeans and trained as stockmen or police-trackers, take women of tribes in less contact with whites. Police-trackers, stockmen, and in the early days of Queensland, native police, were the initiators of this Post-European contact type of intertribal marriage.

A good example observed during the 1938-1939 study is that of a Nangatadjara man, 44 years of age, at Laverton, Western Australia who had worked with whites for 13-14 years prior to 1939. His history shows that about 1930 he took as wife a Ngadadjara woman of one of the southern hordes of that tribe. At this time the main body of Ngadadjara were just coming to be known to whites but were not in close contact with them. Earlier than this the two tribes had not had intermarriages.

Changes in the marriage pattern among disrupted tribes is exemplified by the crop of intertribal marriages which took place after 1935 when the above mentioned Ngadadjara, having found their way into Laverton township, freely gave their womenfolk to men of Europeanized tribes, including some natives who had, for years, been in contact with white men on the Kalgoorlie Goldfields.

TRIBAL AND INTERTRIBAL MARRIAGES—THE 1938-1939 DATA

In the following paragraphs the lists of tribal and intertribal marriages given in the appendix are arbitrarily grouped into several blocks. The areas chosen are those used by us in some other analyses of data on the Harvard-Adelaide Universities Anthropological Expedition and their general distribution is as shown in figure 1.

Taken tribe by tribe these marriage records may not, because of their limited numbers, give a good picture but when gathered into large blocks of tribes they seem to yield a clearer one, and taken together do give some idea of the intertribal marriage opportunities afforded members of some Australian tribes.

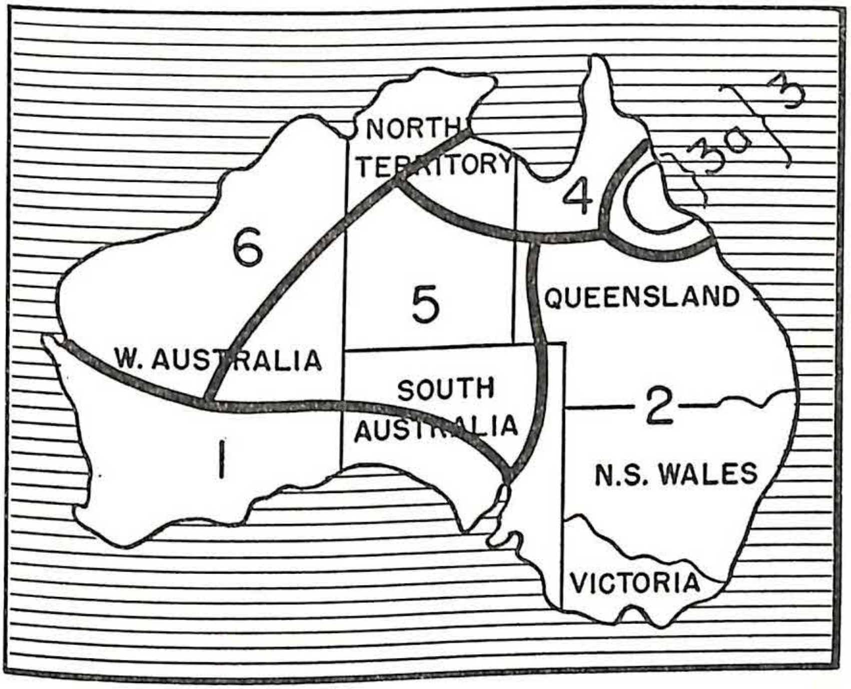

FIG. 1. SIX AREAS USED IN ANALYSING 1938-1939 DATA ON INTER-TRIBAL MARRIAGES.

Of the listed 101 marriages in the Negritic Block of Barrinean peoples as defined by Birdsell ('49) only one chanced to be contracted outside the Central Negritic Block and this between a Barbarian man and a Mulurutji woman of one of the Semi-Negritic tribes whose territory joins his on a small segment of boundary.

In the Negritic plus adjoining Semi-Negritic tribe Blocks, of 150 marriages only one was outside the block and this was a marriage between a Wakaman man and a Kutjal woman (Carpentarian Block). Their tribal territories adjoin on a broad line.

Between the Carpentarian and South Eastern Australian Blocks, which do not join together over any large length of boundary, no intermarriages were recorded in a total of 180 marriages. Between the Carpentarian and Central Blocks also intermarriages were not recorded in 102 listed marriages. Since the usual intertribal marriage is between adjoining tribes or at most the next but one the lack of recorded marriages linking these blocks cannot be said to be very significant.

TABLE 2

Tribal and intertribal marriages

AREAS	TRIBAL MARRIAGES	EXTRA-TRIBAL MARRIAGES	ADJOINING TRIBES	ONE TRIBE REMOVED	TWO TRIBES REMOVED	% EXTRA-TRIBAL MARRIAGES
Whole of data	346	56	50	3	2	14
1 South Western tribes	80	10	10			11
2 South Eastern tribes	59	6	5	1		9
3 Negritic and adjoining tribes	119	31	27	2	2	21
3a Central Negritic tribes without adjoining tribes	81	20	18	1	1	20
4 Carpentarian tribes	80	7	7			8
5 Central tribes	8	2	2			20
6 North Western tribes	not sufficient data					

In the Central Australian Block, of 10 marriages, two were outside the area, one with the South Eastern and one with the South Western Blocks but the information available on these blocks in the Harvard-Adelaide University Anthropological Expedition results is largely for peripheral groups in Queensland and is insufficient alone to furnish sound data although it hints that the known trade routes running in a southwesterly direction through eastern Central Australia may have carried human genes as well as transmitting shell ornaments and stone-axe-blades.

To augment the scant data available for the Central area the following additional data fortunately are available.

TRIBAL AND INTERTRIBAL MARRIAGES—CENTRAL AUSTRALIAN DATA 1930-1932

The present writer, during the 6th, 7th and 8th Expeditions of the Board for Anthropological Research in 1930, 1931 and 1932 gathered data on tribal and intertribal marriages among 8 Central Australian tribes. The information came during the routine registration of the aborigines for the taking of anthropometric measurements.

All these tribes are in the "Central Tribes" area of the Harvard-Adelaide Expedition study, and give data for an area in which that series was weak.

TABLE 3

Tribal and intertribal marriages

CENTRAL TRIBES	TRIBAL MARRIAGES	EXTRA-TRIBAL MARRIAGES	ADJOINING TRIBE	ONE TRIBE REMOVED	TWO TRIBES REMOVED	% EXTRA-TRIBAL MARRIAGES
(a) Iliaura	34	3	3			8
(b) Anmatjera	26	5	4	(1 complex; see text)		16
(c) Aranda	4	3	3			data incomplete
(d) Walmala	30	2	1	1		6
(e) Jumu	3	2	2			data incomplete
(f) Kukatja	3	2		2		data incomplete
(g) Ngalia	16	2	2			11
(h) Pintubi	18	3	3			14
Whole of above	134	22	18	4 (one is complex).		14
Above (excluding Aranda, Jumu, and Kukatja three tribes with incomplete data)	124	15	13	2 (one is complex).		11
Groups speaking Aranda type language (a, b, c, d)	94	13	11	2 (one is complex).		12
Groups speaking Pitjandjara type languages (e, f, g, h)	40	9	7	2		18

The Ngalia listed here are in part the same subjects as appear in the first part of this study and represent an independently gathered set of data serving as a general cross-check on the results of that study.

The Iliaura listed in the above table form a compact tribal group whose only three extra-tribal marriages were with Aranda and these were confined to one Aranda family line, the Iliaura having supplied wives for at least two successive generations of one eastern Aranda family group. The data for the Iliaura are highly significant.

The Aranda data are not complete enough to be significant since some of the main groups are virtually extinct, and at the time of the study only marginal groups on the borders of other tribes were alive to speak.

For the Anmatjera the data are sound. One very interesting case was encountered where an old Anmatjera man was married to a woman who spoke Anmatjera, having been reared as one, but her parents had been Kukatja and Ngalia. This was an early intertribal marriage; it long antedates the main period of European contact. A further intertribal marriage occurred in the following generation in the same family line.

A rather different case is that of an Anmatjera man, now old, who in his youth left his tribe and lived as a Walmala. His wife in this case was an Aranda woman. Apparently he had stolen her, fled his country, and lived to rear a family. Kukatja and Aranda people and in later years and to a lesser extent the Anmatjera have been influenced by Hermannsburg Mission. Hence this case may not be as free of white man's influence as appears at first sight.

European contacts can be entirely ruled out as factors influencing the data for the Walmala, Jumu, Ngalia and Pintubi tribes since these tribes had only lately encountered white men, other than explorers, at the time the study was made.

One Pintubi intertribal marriage, with a woman of the Wenamba tribe, is of particular interest. People of the last named tribe live to the west of the Pintubi and were not (even in 1951) in known close contact with Europeans. When the data were being gathered the Pintubi themselves were not under any European influences. In actual fact not even the proper name of the Wenamba tribe was known till 1951.

One Pintubi intertribal marriage, with a Pitjandjara woman, appears to be a counterpart of the Pitjandjara exchange marriage with a Pintubi woman noted during the 1933 Expedition in the Mann Range. In that instance a Pitjandjara man was recorded as having obtained in marriage a Pintubi woman plus her "unwanted" store of wooden tjurunga, which it was her husband's duty to care for and secrete from her. Both these alliances took place beyond any area of even remote European influences; any contacts they had had being confined to ephemeral ones during the passage of explorers through their country.

The data for the Jumu, being based on eastern marginal hordes only, is probably not fully representative. The two listed Jumu intertribal marriages are in successive generations and are connected, the circumstances being known. A Jumu man married a Ngalia woman. His son married a Kukatja. In this son's progeny there are thus represented Ngalia, Jumu and Kukatja genes. All the listed Jumu marriages can be regarded as free of European influences since the Jumu were much later than other tribes in coming into contact with Hermannsburg Mission. Incidentally, as showing the changes wrought by the impact of our white civilization, it is to be noted that one of the male descendants of the above "three-tribes-union" is now (1951) a cattle hand at Marree, living habitually 500 miles to the southeast of his father's country.

CONCLUSIONS

Drawing together the threads of the three groups of studies it seems evident that there are grounds for assuming that about 15% of Australian aboriginal marriages may transgress tribal boundaries and thus may introduce not only new genes but also new dialect and language forms, as well as any cultural items which have not chanced to spread more rapidly as the result of culture contact, copying and imitation.

The significance of such opportunities for slow and perhaps inexorable spread of human genes must be evident to all and may suggest that no primitive human group when in physical contact with another can remain to itself, unchanged, however conservative it may try to be. There is no inherent reason why, given time, any attribute associated with *Homo sapiens* may not spread to all.

One may recall that over the vastness of time represented by a "Mindel" or a "Riss Ice Age" or by a "Great Interglacial" the making of more than one type of *coup-de-poing* and blade implement seems to have spread from the tip of Africa to the top of Europe perhaps not once but several times. Doubtless human genes do the same, but more slowly.

A 15% intertribal marriage rate means a maximum gene flow of 7.5%. Since Australia is about 12 to 15 tribal areas wide in a north to south direction and 25 tribes long in an east to west direction the evident physical differences in various parts of the continent have not been affected very quickly.

ACKNOWLEDGMENTS

I am indebted to numerous colleagues on the various teams which have worked in the anthropometric field including: A. A. Abbie, J. B. Birdsell, T. D. Campbell, J. B. Cleland, H. K. Fry, the late H. Gray, C. J. Hackett, and the late T. H. Johnston. Various aspects of the problem have come up for discussion with them and for critical appraisal. Their view points often have provided the stimulus to thought and action in gathering the data given herein. However the work of gathering and assessing the data has been exclusively that of the writer who therefore is responsible for any errors it may contain.

SUMMARY

This paper arrives at the conclusion that among the Australian aborigines about 15% of marriages are intertribal. In a series of large blocks of tribes the percentages of recorded intertribal marriages range from about 7% to 21%.

On the available data the rate of intertribal marriages happens to be high (20%) within a block embracing the Atherton Tableland in Queensland, where the Barrinean (Tasmanoid or Negritoid) peoples predominate. It is much lower (about 10%) among the Southern coastal tribes of typically Murrayian stock and is around 15% over much of Central Australia although in the Ngalia tribal area, studied in greatest detail, it stands lower (at about 8%). For the Carpentarian areas of the North relatively meager data implies intertribal marriages of the order of 8%.

Evidence is offered for the general validity of the data presented and the conclusions reached.

The data as a whole are based on analyses of about 760 marriages among fullbloods where the accompanying information indicated the probability that the marriage was free from disruptive European influences.

Physical anthropologists working on genetics need information on the factors influencing human population structure. The hunting and food gathering people of Australia tend to live in tribal units with breeding communities of the general order of 150 to 600 individuals. Populations of this size seem sufficiently small to suggest the possibilities of the occurrence of random genetic drift, which may be presumed to occur if the rates of selection are not too high and if the

rate of gene exchange between the breeding communities is low. It would seem important therefore to understand the degree of intergroup contact that may exist among the various tribes.

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APPENDIX

LIST OF TRIBAL AND INTERTRIBAL MARRIAGES, AS RECORDED BY HARVARD-ADELAIDE UNIVERSITIES ANTHROPOLOGICAL EXPEDITION.

TRIBE	TRIBAL MARRIAGES	INTERTRIBAL MARRIAGES
1 SOUTH WESTERN TRIBES		
Wudjari	6	
Minang	2	
Koreng	1	
Kalamai	6	
Widi	1	
Ngaluma	1	
Kalarko	1	
Ngadjunma	11	1 Mirning (adjoining tribe) 1 Kalarko (adjoining tribe) 1 Tjeraridjal (adjoining tribe)
Waljen	1	
Murunitja	1	
Tjeraridjal	2	1 Ngadjunma (adjoining tribe)
Wirangu	4	
Mirning	5	
Tjalkadjara	1	1 Nangatadjara (adjoining tribe) (linked in with pushing of Tjalkadjara tribe westwards from Darlot c 1880-90 by Nangatadjara)
Nangatadjara	14	1 Wongaii (adjoining tribe) 2 Mandjindja in successive generations; both prior to European influence (adjoining tribes)
Mandjindja	9	1 Nangatadjara (adjoining tribe)
Ngadadjara	7	
Ngalea	1	
Kokata	6	1 Ngalea (adjoining tribe)

TRIBE	TRIBAL MARRIAGES	INTERTRIBAL MARRIAGES
2 South Eastern Tribes		
Dainggata	1	
Kumbainggiri	1	
Kunggari	14	1 Mandandanji (adjoining tribe)
Koamu	3	
Batjala	2	
Korenggoreng	3	
Kangulu	3	
Ngoera		1 Wakawaka (adjoining tribe)
Darambal	1	
Wakawaka	3	
Kabikabi	1	
Pitjara	1	
Kairi		1 Wadja (separated by 1 tribe, the Kangulu)
Ngaro	2	
Wiri	4	1 Jangga (adjoining tribe) 2 Biria (adjoining tribe)
Biria	1	
Kutjala	1	
Barada	3	
Jirandali	1	
Kalali	4	
Kalkadung	4	
Ringu ringu	1	
Maljangapa	1	
Marukanji	1	
Karuwali	1	
Kuungkari	1	
Koa	1	
3 Negritic and Adjoining Tribes		
Wulgurukaba	2	
Warkamai	7	
Keramai	9	3 Gulngai (adjoining tribe) Warkamai (adjoining tribe)
Nawagi	3	1 Mamu (not contiguous tribes but both rain-forest peoples) 2 Djiru (adjoining island tribe)
Djirubal	7	1 Ngatjan (adjoining tribe) 4 Gulngai (adjoining tribe)
Ngatjan	4	5 Djirubal, Mamu, Idindji (all adjoining tribes)
Mamu	9	2 Idindji, Gulngai (adjonining tribes)
Gulngai	4	1 Djirubal (adjoining tribe)

TRIBE	TRIBAL MARRIAGES	INTERTRIBAL MARRIAGES
Djiru	3	2 Mamu adjoining and Idindji not contiguous (periods 1890-1895)
Idindji	12	2 Ngatjan (adjoining tribe) 1 Djirubal (separated by Ngatjan tribe)
Wanjuru	2	
Kongkandji	15	
Tjapukai	17	1 Buluwai (adjoining tribe)
Buluwai	2	
Barbaram	6	1 Muluritji (adjoining tribe, linked on small segment of boundary)
Irukandji		1 Tjapukai (adjoining tribe)
Kokobididji	1	1 Jungkurara (adjoining tribe)
Agwamin	2	1 Barbaram (not adjoining tribe, separated by Wakaman tribe)
Kokojelandji	3	
Muluritji	7	1 Walpura (adjoining tribe) 1 Tjapukai (adjoining tribe) fathers's father was of mixed Muluritji X Tjapukai origin
Kokobujundji	1	
Walpura	1	
Wakaman	2	1 Kutjal (adjoining tribe)
4 CARPENTARIAN TRIBES		
Koko Imudji	8	
Koko Jawa	2	
Bakanambia	2	
Wanji	6	1 Maikudung (adjoining tribe)
Ngaun	4	
Kukatji	2	
Jokula	3	
Maikudung	2	
Karawa	1	
Lardiil	1	
Kokomini	5	
Tagalag	3	
Walagama	2	2 Maikulung (adjoining tribe)
Araba	1	
Kunggara	9	
Konanin	4	
Wikmunkan	1	
Wikngatara		1 Wikmunkan (adjoining tribe)
Ombila	3	1 Kandju (adjoining tribe)
Kandju	13	2 Ombila and Aijabatha (adjoining tribes)

TRIBE	TRIBAL MARRIAGES	INTERTRIBAL MARRIAGES
Ankamuti	1	
Winduwinda	2	
Pakadji	1	
Ngundjan	3	
Olkulo	1	
5 CENTRAL TRIBES		
Pitjandjara	1	1 Ngadadjara (adjoining tribe)
Waramanga	1	
Jangkundjara	1	
Antakirinja	1	
Aranda	2	
Wakaia	1	1 Kalkadung (adjoining tribe with very limited common boundary)
Ngalia	1	
6 NORTH WESTERN TRIBES		
Njikena	1	

DEMOGRAPHIC PATTERNS IN THE PAPAGO INDIAN VILLAGE OF CHUICHU, ARIZONA

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INTRODUCTION

DURING the summer of 1952 an ecological study was conducted in the village of Chuichu, Arizona, a community of 223 inhabitants situated some 60 miles south of Phoenix on the northern edge of the Papago Indian reservation. Since the demographic material seemed to have intrinsic value, it is presented here for comparative purposes. Where feasible, statistical tests have been applied; where not, the findings are presented as they stand for use by those concerned with groups of similar size.

VILLAGE POPULATION

The most accurate count of Papagos living on reservations was made in 1942 when war ration books were issued. At that time 6,494 were enumerated. In 1910 and 1930, the Bureau of the Census listed 3,798 and 5,205 respectively. The most recent estimate of 7,377, as of 1950, comes from House Report No. 2503 (82nd Congress, 2nd Session, '52). These 4 figures over the past 40 years indicate a 98% tribal increase, or an annual rate of about 1.7%.

For the village of Chuichu, the 1942 ration count revealed 136, although the proportion of the total year these people actually lived in the village is not known. In 1952, the writer counted 223 people all of whom had been residents for 6 months or more of the preceding year. Of the 48 married couples making up this population, 26 had spent the entire time at home, 15 had been employed away from the village for one to three months, and 7 had had outside employment from 4 to 6 months.

The federal census defines the family as two or more persons related by blood, marriage, or adoption residing together; and the primary family as the head of household together with all others in the house related to him. Since no unrelated persons were living in any household in Chuichu either in 1942 or in 1952, the words "family," "primary family," and "household," can be used interchangeably. In 1942, 6 households contained widowed grandparents, and 5 contained related persons other than sons, daughters, and their children. In 1952, widowed grandparents were present in two households other than their own, while 5 households contained relatives other than sons, daughters, and their children. Blood relationships and marriage connections from household to household were quite similar, unlike the varied character of household composition found by Beaglehole ('35) in 1934 census data from two comparably-sized Hopi Indian villages.[1] There has also been a growing tendency for Papago households to contain only two generations rather than the traditional three, a trend noted by Joseph, Spicer, and Chesky ('49) in certain other parts of the reservation.

With the 1942 and 1952 population figures as a basis, some indication of the demographic situation in Chuichu is possible. During the decade, the rapid growth of the village stands out. Fifty-two people have migrated from other communities:

new households (6)	36
new wives	8
new husbands	3
divorced woman and son	2
grandmother	1
orphaned niece	1
adult daughter	1
	52

Including the offspring of these new families since their immigration, 69 children have been born since 1942, making the total gross population increase 121. Over these same years, there have been 29 deaths and 5 emigrations. Thus, the net increase has been 87, or 64%, an average increase per annum of 5.2%. Part of this increase is a reflection of a high number of recent marriages. Between 1942 and 1950 there were 5, and since 1950 there have been 7. All but one of these unions brought a new individual to Chuichu.

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[1] Hopi social structure is oriented in the female line. Typically, husbands reside in the household circle of the wife's family. The opposite is generally true in Papago society.

Within the village itself, there have been 56 known changes of residence and undoubtedly more have occurred. These shifts have been brought about by parents leaving their children in a relative's care while they left Chuichu for wage work, by periodic reshuffling of households to meet space and living problems, by three divorces, and one new marriage within the village.

In 1942, there were 32 households, averaging 4.25 persons per house. In the ensuing 10 years, 5 of these units dissolved, but 15 new ones were created so that 42 existed in 1952, averaging 5.31 persons each. The size of household at present is almost identical with the tribal estimate of 5.3 made by the Secretary of the Interior in 1949, but biological family size is smaller: 4.1. Of the 27 households intact throughout the period, 5 declined in size, 5 remained stationary, and 17 increased. At the present time there is a concentration around the number of 5 per household. Individual homes range in size from one to 13, but only 7 contained more than 7 people, and only 6 contained less than three.[2]

Whereas the birth dates of the children born since 1942 are known, the death dates of those dying between 1942 and 1950 are unknown. Thus, crude birth and death rates must rest partly on estimation. The 1942 population, less emigration since that year, reveals 131 people who have lived in Chuichu continuously between 1942 and 1950. To this group 31 children were born, and of it 16 died, making the net increase 15. With this information, birth and death rates have been computed in table 1 for the 7-year period, 1942-1949, and for the three-year period, 1950-1952, during which time both birth and death dates were known.

TABLE 1

Crude birth and death rates

YEAR	VILLAGE POPULATION	NO. OF BIRTHS	BIRTH RATE PER 1000	NO. OF DEATHS	DEATH RATE PER 1000
1942-1949 (average)	131	4.4	33.8	2.3	17.6
1950-1952 (average)	201	6.7	33.3	3.0	14.4
Tribal rate (1942)			42.3		32.3
U. S. rate (1950)			23.5		9.6

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[2] In Beaglehole's census among the Hopi in 1934, household size was considerably larger (6.5), and there was little concentration in the size of individual households.

From the foregoing, it will be seen that both birth and death rates for the village are lower than for the tribe, and that the death rate especially is moving away from any similarity. Whether the tribal pattern in the last 10 years has changed in like manner is not known.

It is not possible with the information available to determine life expectancy in the village. For the tribe, based on an estimation of the number of infants born and the proportion still living at later ages, life expectancy in 1942 was considered to be 17 years (Department of the Interior, '49). Infant and child mortality are recognized to be high, and if the total number of deaths of infants in the first few weeks of life were accurately known, the life span might have been even lower. In Chuichu, the average age at death in the past 10 years was 37.7 years, but there is lack of concentration around this figure. If the Papago survives adolescence, he is likely to live a good long time. In fact, the number of old people is remarkably high. Six of the deaths in the village in the last 10 years were of people presumably over 80. Now present in Chuichu are 13 people who are probably at least 70 years of age. Deaths in the middle years appear to be heavier for men than for women partly the result of accidents incident to occupation.

TABLE 2

Ages at death (1942-1952)

AGE	NO.	PER CENT
under 5	9	31.0
5– 9	2	6.9
10–14	2	6.9
15–19	2	6.9
20–65	3	10.4
over 65	11	37.9

Another peculiarity in the birth and death pattern in the village has been the prevailing sex ratio. The small sample and the lack of information on deaths in the early stages of post-natal life make the sex variance of little significance but of enough interest to suggest further investigation on a wider scale.

The village comprises quite a young group although the fertility rate appears to be dropping.

TABLE 3

Sex ratio of births and deaths
(figures based on table 1)

		MALE	FEMALE
Births:	(1942-1949)	15	16
	(1950-1952)	8	12
Child deaths	(1942-1949)	1	4
under 5:	(1950-1952)	0	4
All deaths:	(1942-1949)	4	12
	(1950-1952)	2	7

TABLE 4

Fertility rates

	WOMEN (15-49)	CHILDREN (UNDER 5)	FERTILITY RATE (PER CENT)
Chuichu (1952)	60	31	51.7
Chuichu (1942)	35	19	54.3
Tribe (1942)	1,481	863	58.3
U. S. (1950)[1]	38,552	16,324	42.3

[1] Preliminary estimate (in thousands)

TABLE 5

Population by age groups (in per cent)

AGE	VILLAGE 1952	VILLAGE 1942	TRIBE 1942	UNITED STATES 1950
0–19	47.9	38.5	46.5	34.4
20–39	26.0	37.8	29.9	30.6
40–59	17.8	10.4	13.8	22.9
60–over	8.3	13.3	9.8	12.1
	100.0	100.0	100.0	100.0

The age distribution of the 1952 Chuichu population follows the tribal pattern quite closely, but both groups are different from the village in 1942 and from the present distribution for the United States as a whole.

On the basis of the distribution in the above age groupings for the United States in 1950 and 1940, expected frequencies were computed. These were compared with the village and tribal observations, and the Chi-square test applied. For the groups as a whole for three degrees of freedom, the values for both tribe and village (1942 and 1952) are significant at the one per cent level. Combining the cases for the village in the two census years and repeating the test revealed significant variance in the two samples at the two per cent level. Although the 1952 village was not found to be significantly different from the tribe, the 1942 village is significant at the 5% level. An attempt was also made to ascertain if the current age distribution of the tribe and village matched any past U. S. census year between 1850 and 1950. For the village in 1952 and for the tribe, the closest resemblances occurred with 1880 through 1910.[3] No causes for this were established, but certain factors in the U. S. population such as the inclusion of former slaves with the white population after 1860 and high immigration during those years may have some bearing. The 1942 village distribution showed no discernible pattern compared with past U. S. census years.

The median age in Chuichu has been dropping and, in 1952, corresponded to the United States median of 1890.

TABLE 6

Median age

YEAR	VILLAGE	TRIBE	UNITED STATES
1952	21.0	——	30.1 (1950)
1942	26.5	22.1	28.9 (1940)

As in the U. S. population, the median age for males in both village and tribe is slightly higher than for females. Due to the long span of life of many of the villagers, once adolescence is survived, mean age is closer to the present United States mean than to the median.

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[3] Although the village values were not significantly different from total United States figures for these years, tribal values were still significant at the one per cent level, and the village and tribe followed trends similar to each other.

The sex ratio by broad age groupings, particularly for the village, tends to reverse the pattern prevailing in the U. S. as a whole. Among those under 40, females outnumber males, but over 40 the opposite is true.

TABLE 7

Mean age

YEAR	VILLAGE	TRIBE	UNITED STATES
1952	26.9	——	31.1 (1950)
1942	28.8	26.3	29.6 (1940)

TABLE 8

Sex ratio by age groups (in per cent)

AGE	VILLAGE 1952		VILLAGE 1942		TRIBE 1942		UNITED STATES 1950	
	Male	Female	Male	Female	Male	Female	Male	Female
0–19	48.6	51.4	50.0	50.0	49.2	50.8	50.5	49.5
20–39	42.1	57.9	47.1	52.9	50.1	49.9	48.9	51.1
40–59	56.4	43.6	64.3	35.7	53.5	46.5	49.8	50.2
60–over	61.1	38.9	50.0	50.0	57.3	42.7	47.8	52.2

Again on the basis of the sex divisions in each age group for the United States in 1950 and 1940, expected frequencies were computed and compared with the observed in both the village and tribe. The Chi-square test was then made. For the groups as a whole for 4 degrees of freedom, the values for the tribe were significant at the one per cent level. The values for the village in both 1952 and 1942, however, fell short of the 5% level. As with age distribution, the tribal sex division most closely matched the U. S. in the census years 1880 through 1910, but the values were still significant at the 5% level. On the other hand, village sex division followed no pattern of close resemblance to any past U. S. census year, but the values were not significant.

Broken down by size of biological family, the village sample becomes exceedingly small, but if the figures are indicative, the average family size is surprisingly low, weighted in part by the large proportion of recent marriages. In only 5 families were there 5 or more children living with their parents, the highest number being 7. The figures, however, may not represent all children under 21 since some may have been living with relatives away from the village. In the case of some families, there are gaps of as much as 10 years between the ages of children, indicating high mortality in the early years of life.

TABLE 9

Size of family

CHILDREN UNDER 21	1942 FAMILIES		1942 FAMILIES PRESENT IN 1952		ALL 1952 FAMILIES	
	No.	%	No.	%	No.	%
none	8	25.0	8	27.6	12	25.0
1	7	21.9	3	10.3	12	25.0
2	12	37.5	5	17.2	6	12.5
3	5	15.6	3	10.3	5	10.4
4			6	20.6	8	16.6
5			1	3.5	1	2.1
6			2	7.0	3	6.3
7			1	3.5	1	2.1
	32	100.0	29	100.0	48	100.0

Marriage is the normal state for adult Papagos, but Chuichu appears to have a relatively high proportion of unattached people. Of those 21 or over, 20.2% were unattached in 1952.

	Male	*Female*
Single (21 or over)	4	8
Divorced	1	4
Widowed (all over 50)	3	2

The reliability of the birth dates of the Chuichu population should be mentioned. Although Papagos are familiar with relative ages since kinship terms and behavior patterns have been linked to them (Joseph, Spicer, and Chesky, '49), exact ages have had little cultural significance. Now, of course, under the influence of school rolls, the war, census taking, and old-age benefits, the knowledge of proper ages has become useful and necessary for these people. In Chuichu the transition is well along, but it will be at least another generation before birth dates become accurately known for all ages. When ration books were issued in 1942, the government made an effort to determine birth dates. In the summer of 1952, the writer checked school rolls and questioned people as to their ages. With these various sources of information, some check on age accuracy was possible. If age checked in two or more cases, it was considered correct.

TABLE 10

Age accuracy

AGE	CORRECT	INCORRECT	DON'T KNOW [1]
under 21	110	2	0
21–39	12	23	15
40–over	13	32	14
Don't know [1]	0	0	2

[1] "Don't know" means that only one or no sources of information were available.

From the preceding, it can be seen that by far the greatest accuracy prevails among those under 21 years of age. Of those apparently misstating their ages, where recheck was possible, the standard deviation of the distribution of misstatements was 4.25 years, with a mean of — .035 of a year.

DISCUSSION

There is no doubt that more people are now residing in the village than at any time in recent years. To a large extent, the influx from outside areas and the high proportion of new marriages can be accounted for by improved economic conditions. Favorable underground water supply for irrigation farming, successful cotton crops harvested cooperatively in the past several years, increased income from rental of pastures, and the convenient location of the village to surrounding Arizona farms where wage work can be secured, have all helped to give Chuichu a new reputation as a promising place in which to live.

The long-standing migratory pattern of Papagos, however, may mean that this relatively large population increase is only temporary. Families who have come from surrounding communities undoubtedly hold land and may still continue to graze cattle near their former homes; but the fact that these families, who have swelled Chuichu nearly 25%, hold only 5% of the local land, seems to indicate that the possibility of a higher standard of living has drawn them there. On the other hand, all of the new families in the village are closely related in some way to the existing population. Unrelated people still do not move easily into a Papago village, nor do those in a village readily leave. Thus, the factor of close inter-family relationship may act as a check on future immigration unless it is outweighed by a continuation of the recent economic improvements.

The birth rate in Chuichu has been somewhat below that for the tribe and appears to have remained quite steady over the past decade. A slightly higher proportion of families in 1952 had less than two children than was the case 10 years earlier but, at the same time, a considerably higher proportion of 1952 families were biologically uncompleted.

Noteworthy is the relatively low death rate that prevails. Clean water from pumped sources since 1923 has undoubtedly given Chuichu a health position superior to that of many Papago villages where pumped water is either a more recent development or is much less accessible for daily needs. The medicine man's art is dying out in most Papago villages and is not in evidence in Chuichu. Although modern medicine is not fully accepted or sought by the residents, an increasing number of families are using the facilities in Casa Grande, less than 10 miles away. Principally due to increasing changes for longer life, natural increase has gone up.

TABLE 11

Natural increase

	PER CENT
Chuichu (1950-1952 average)	18.9
Chuichu (1942-1949 average)	16.2
Tribe (1942)	10.0

In respect to age distribution and sex division, both the tribe and village comprise groups rather different from the present U. S. population according to the computed values of Chi-square. Moreover, in age distribution, the village itself has changed significantly since 1942. In the past, the physical environment of the Papagos has been relatively isolated. Each community has tended to be a natural, closely-knit unit indulging in comparatively little communication with other communities except the very closest ones. Now, with better roads, more facilities for communication, more interest and concern for both tribal and federal government at Sells, in the heart of the main reservation, and with less isolation between Papagos and Arizona society at large, village social patterns are changing. In Chuichu, at least, these changes are being reflected in the population make-up. Indicative is the fact that 19 of the present spouses in the village are from outside communities, 5 of them having made their original homes more than 50 miles away. Of these outside marriages, 60% have occurred in the last decade.

Past records are scanty, but indications are that the Chuichu demographic pattern was following its own rather unique and stable course as recently as 1942. But with important social and economic changes since the war, and especially if land improvement plans for this area take place in the near future (Department of the Interior, '49), it is likely that population characteristics will continue to show marked changes but tend to become more rather than less like the nation's population as a whole.

SUMMARY

The Papago village of Chuichu, Arizona, in the past decade reveals a per annum population increase of 5.2%. In these same years, the birth rate has remained steady, but the death rate has dropped appreciably and length of life has increased. For the Papago tribe as a whole in 1942, and for Chuichu in 1952, age distribution is shown to be significantly at variance with present U. S. distribution. Age groupings within the village, itself, have also changed significantly in the last 10 years. Sex divisions by age groupings for the tribe are unlike the U. S. but statistically this is not significant for the village.

ACKNOWLEDGMENTS

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NOTE ON THE FERTILITY OF A NUMBER OF WOMEN OF THE ANCIENT NEAR EAST

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INTRODUCTION

IN the course of other research, the following material on the fertility of women of the Bible and the Apocrypha was assembled. Data were also found for a number of Macedonian, Seleucid, and Ptolemaic queens.

There are few cases in the Bible and the Apocrypha in which we know the total number of sons and daughters of a woman, but in several instances we have a fair assurance of how many sons she had. The following data, therefore, are given in number of sons.

DISCUSSION

In the 2,000 years covered by the Bible from the time of Abraham in 1900 B. C. to the destruction of Jerusalem and the martyrdom of Paul in the 1st century A. D., we can count 43 women who had a total of 119 sons. The average number of sons per woman is 2.8. If we compare this with the number of sons of a Palestinian woman in the century between 1830 and 1930 A. D., we find some difference.

Hilma Granqvist's study made in the village of Artās, south of Bethlehem, between 1925 and 1931 gives the genealogies of all the families of the village for 4 generations (Granqvist '31). Because polygyny is still practiced and because the genealogies are traced through the male line, counting the number of sons per woman has not always been possible. (The number of daughters is not given.) However, we can tell from these charts the number of wives in each household and thus determine the average number of children for the total number of women.

Only those women who were dead were considered in order to be sure that their families were completed. The count showed that 60 Artās women had 95 sons or an average of 1.6 sons per woman. These women, then, had one son less than the average Biblical woman.

By restricting the count to the 29 monogamous families of Artās, it was possible to determine the number of sons that each woman had. Twenty-nine monogamous women had 48 sons—that is slightly over 1.6 sons per woman.

Table 1 shows that the highest percentage of Biblical women fall in the two and three son brackets. In the Palestinian village, however, the greatest proportion of women is found in the lower brackets of zero sons, one son, and two sons. The number having one son is markedly high.

TABLE 1

Number of sons of 43 Biblical women, 29 monogamous Artās women, and 34 Macedonian, Seleucid, and Ptolemaic Queens.

NUMBER OF SONS	BIBLICAL		ARTĀS		MACEDONIAN, SELEUCID AND PTOLEMAIC QUEENS	
	Number of women	Per cent	Number of women	Per cent	Number of women	Per cent
0	4	9.3	6	20.7	6	17.7
1	7	16.3	10	34.4	7	20.6
2	11	25.8	6	20.7	13	38.2
3	9	20.9	4	13.8	5	14.7
4	4	9.3	1	3.5	2	5.9
5	3	6.9	2	6.9	1	2.9
6	3	6.9	—	—	—	—
7	2	4.6	—	—	—	—
Totals	43	100.0	29	100.0	34	100.0

Table 1 also gives the fertility of a number of women who ruled in the Macedonian, Seleucid, and Ptolemaic empires from the 5th to the 1st centuries B. C. (Macurdy '32).

In all, there are 34 women with 61 sons and 34 daughters. Again we shall refer only to sons because the number of daughters is uncertain.

The average number of sons of these Hellenistic women is approximately 1.8, or one son less than that of the Biblical women. This figure is not far from the number of sons of the modern Palestinian women, which averaged 1.6. Table 1 shows the family size of the Hellenistic women, which appears to be intermediate between that of the Biblical women and the modern Palestinian women.

Six of the Ptolemaic queens, whose fertility we know about, were married to their brothers, but they do not appear to have been less fertile than the other queens. The possibility of infants being brought up in the palace as the queen's children in the absence of true heirs cannot be discounted as a possibility, however. It is doubtful whether the queens had a characteristic fertility considering the violence and extraordinary conditions of their lives, and unfortunately no material was found which would give the fertility of another group of Hellenistic women, or even of modern Greek or Egyptian peasant women.

CONCLUSION

Although the historical data are too fragmentary to reveal very much about fertility in the ancient Near East, it appears that the fertility of women of the Bible and Apocrypha was higher than that of more modern women living in the same area. Those Macedonian, Seleucid, and Ptolemaic queens for whom we have a record of offspring show a fertility between that of the ancient and modern Palestinian women.

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THE SOCIAL BIOLOGY OF VERY HIGH FERTILITY AMONG THE HUTTERITES
THE DEMOGRAPHY OF A UNIQUE POPULATION

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INTRODUCTION

THE ethnic Hutterites of North America provide an exceptional opportunity to study social and biological aspects of human fertility and reproduction. It is well known that in technologically advanced countries, where population statistics are adequate, the population does not increase under sufficiently stable and unplanned conditions to use demographic data as an ex post facto experiment in human biology. In groups where there is little migration, where no birth-control measures are used and where reproduction proceeds without conscious planning, vital statistics are usually unreliable. Hutterite vital statistics are an exception to this generalization.

The group is an anabaptist religious sect, living in the United States and Canada in small self-contained hamlets, which they call colonies. Within each colony, and throughout the entire population, there is a high degree of homogeneity in socio-economic status, educational level and other social attributes. Between 1880 and 1950 the sect has increased over 19 times, from 443 to 8,542 persons. This growth has largely been the result of natural increase. Excellent records are available covering more than the last 70 years of the group's history. During this 70 year period, fertility patterns through time could be observed almost entirely unaffected by some of the common social factors as migration, birth-control practices and changing marriage patterns.

The Hutterite population is reproducing itself close to the theoretical maximum level of human fertility for all but the 15-19 year age group. To some extent the biological and social factors in human population growth can be observed separately.

The vital statistics were obtained in the process of a general culture-personality study.[1] The research was not planned primarily for demographic purposes. It was designed, as its title indicates, to explore the "Cultural and Psychiatric factors in the Social Life of the Hutterites." Extensive demographic information was collected for ancillary purposes. It was needed to make an adequate description of the group and to calculate rates of mental disorders. Complete censuses of the entire population were available for June 1880 and December 31, 1950. For the intervening years there were 9 population estimates. Family records for 80% of the population in 1950 were the basis of the detailed fertility data. Many internal checks could be made to test the accuracy and representativeness of these records, which are kept by the preacher of each colony as well as by the head of each family in the "Family Bible."

POPULATION GROWTH

The 1880 Base Line

Census taking in this country is a constitutional requirement to provide for a decennial reapportionment of congressional representatives and direct taxes on a population basis (Constitution of the United States, Article I, Section 2, 1789). In the hot summer weather of June in 1880, census enumerators rode across the recently settled plains of the Dakota Territory to gather information for the tenth official census of the United States. In contrast to previous censuses, made during the first century of the Republic, the census of 1880 incorporated requirements to train the enumerators to achieve greater accuracy. It was more adequate technically than the previous American censuses (Wright, '00).

Since 1870, the date of the previous enumeration, the Dakota plains had received many pioneer immigrants. Among them were almost all the Hutterites of the world. This protestant sect had its origin in Switzerland and Bohemia in 1528. Its leaders were among the most prolific writers of religious tracts of the reformation period. At the end of the sixteenth century the group was estimated to have 12,000 to 15,000 adherants (Horsch, '31). During the next two centuries they were severely persecuted by both Catholic and Protestant rulers. By 1762 the sect was nearly exterminated. Only about 60 of the faithful survived to find refuge in Russia under the religiously tolerant regime of Catherine the Great.

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[1] The general plan of the study was reported by Eaton, Weil and Kaplan ('51). The first final report of some of the findings has been completed and is scheduled for publication in the Spring of 1954 by the Free Press with the title of *Culture and Mental Disorders*.

Between 1874 and 1877, practically all Hutterites, afraid of renewed religious persecution, left Russia where they had been living in three Crimean villages (Zieglschmid, '47). They settled in south-eastern South Dakota. Some of them took advantage of the Homestead Act to acquire free land. Others, estimated at somewhat less than half of their total number, bought large tracts of land to build 4 hamlets, each of which was organized on a communal basis. They were the orthodox branch of the sect. They wanted to live up to one of the basic precepts of their religion which regards all private property as sinful.

We could not help but be impressed by the fact that science is a cumulative product, as we checked over photostatic copies of the fading, neatly penned census records. Census agents Charles McCollum, John R. Maxwell and Miles T. Wolley called on these small cohesive groups, the ancestors of all contemporary colony Hutterites in the United States and Canada. The conscientious work of these officials, now long dead, greatly increased the opportunities for verifying our findings. They enumerated 443 colony Hutterites. Their records furnish the name, age, sex, race, occupation, place of birth and place of residence. The distinctive features of the group seemed to have impressed the census takers. Several times they went beyond their instructions to record: "This group speaks, reads and writes the original German language." or "Here ends the Elmspring (or Wolf-Creek) Russian Mennonite Colony." The accurateness of their reports has been verified against complete population data on many of these families found in Hutterite family bibles and colony records.

Our enumeration of Hutterites was also facilitated by the distinctive patronyms of the group and their almost uniform pattern of assigning first names and middle initials. The first son is usually named after the father, the first daughter after the mother; all children use the initial of their mother's name. Seventy percent of the 443 colony Hutterites in 1880 had one of 5 names: Hofer, Waldner, Stahl, Walter or Wipf. Ten other patronyms accounted for the remainder of the group.[2]

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[2] Kleinsasser, Wurz, Gross, Entz, Wollman, Mandel, Decker, Knels, Glanzer

The accuracy of the enumeration process, which underlies our demographic data, can be illustrated by showing how it was possible to identify the Tripp Colony in the 1880 census, although it was not referred to by this name by the census taker.

From Hutterite records, we knew that there was a small settlement near Tripp, South Dakota, settled for a few seasons by members of the Bon Homme Society. Unfortunately, the exact location of this colony or the identity of its members was unknown. As a result, these people had probably not been included in any of the estimates of the population of Hutterite colonies made by previous writers.[3]

We knew from Hutterite records that the spiritual head of the "Hutterische Society, Bon Homme County" was a Reverend Michel Waldner. He was not found to be registered there when we examined the 1880 census microfilms. The question therefore arose: Where was this patriarch on the enumeration date, the 16th of June, 1880? Why was he excluded from the census record of his flock?

His name appeared later as we looked at a page in the census microfilm of Hutchinson County. He was not identified as a preacher, but as a farmer. All Hutterite preachers have some other occupation. However, his birthdate and those of his family checked completely with those recorded in the Bon Homme church register. He was listed with ten other farmers as living in *one* dwelling house. All had Hutterite names. Most of them were on lists in our files, which had been obtained from various Hutterite records.

The data contained in the 1880 census permitted us in turn to address specific questions to contemporary Hutterites, resulting in nearly complete clarification of the identity of the ancestors of the entire 1950 population.

The names and location of the four colonies in existence in 1880 are shown in table 1; their population by age and sex are given in

and Jensen. There were no families with the last name of Jensen in 1950, because the lone family in 1880 had no sons to perpetuate the patronym. There were however, many families named Tschetter, descendants of three large families who joined the colony Hutterites between 1883 and 1892.

[3] There are several published estimates of the population of the original Hutterite colonies in North America. They vary from 250 to 350. See Hofer ('46); Arndt ('44); Deets ('39); and Horsch ('31). The estimates, although based on partial reports, were usually quite accurate for the segment of the population to which they applied. Until recently, when the 1880 census was made available to us, there was no way of checking the accuracy of these estimates.

table 2. The following demographic characteristics should be noted, although the total number of persons in each of the age groups is small.

TABLE 1

List of Hutterite Colonies in June 1880 [1]

NAME OF COLONY	YEAR OF SETTLEMENT	LOCATION	POPULATION JUNE 1880	KINSHIP GROUP [2]
Bon Homme	1874	Bon Homme County, Township 93, Range 59	139	Schmiedenleut
Tripp	1879	Hutchinson County, Township 97, Range 60	55	Schmiedenleut
Old Elm Spring	1877	Hutchinson County, Township 100, Range 59	112	Lehrerleut
Wolf Creek	1874	Armstrong County,[3] Township 99, Range 57	137	Dariusleut
All Colony Hutterites	1874 to 1879	Southeastern South Dakota	443	

[1] From the 1880 census. Photostatic copies of the original records were made available by the U. S. Census Bureau.

[2] Contemporary Hutterites are composed of three kinship groups, each with considerable in-group consciousness. They have their origin in the population of the first settlements, each of which organized separate branch colonies as they grew in numbers.

[3] Armstrong County is now incorporated in Hutchinson County.

These same characteristics will be found to re-occur with little variation at later periods.

1. The number of males and females are nearly equal (221 to 222). The Hutterites migrated to the United States as complete communities, taking all family members with them. In this respect they differed from many other immigrant groups, who left the old folks in the homeland and where male immigrants tended to exceed females.
2. Males outnumber females in all age groups over 40.

3. Nearly half of the population is under 15 (47%) and 12 persons (2.7%) are over 65 years of age.

The 1950 Benchmark

A complete enumeration of the Hutterite population is also available for December 31, 1950. Official 1950 federal census records are not open for inspection. Census records have been classified as secret since the year 1900, when the present United States Bureau of the Census was organized. Summary population data on the Hutterites could be obtained for the Canadian colonies, but they were outdated and not sufficiently detailed to be adequate for our purpose. The vital statistics needed by the Hutterite Mental Health Study therefore, had to be obtained by making a census of our own, in cooperation with the Hutterites and their elected leaders. The field workers were able to travel in cars which were considerably faster than the horses used by our predecessors in 1880. Nevertheless, the 1950 census was a more complex task. From 4 settlements concentrated in a small corner of south-eastern South Dakota, they had branched out into 93 colonies. As shown on the map in figure

TABLE 2

Distribution of the Hutterite Population by Age and Sex June 1880

AGE	MALE	FEMALE	TOTAL
Under 15	109	103	212
15–19	23	21	44
20–24	15	24	39
25–29	15	15	30
30–34	13	15	28
35–39	6	16	22
40–44	10	7	17
45–49	11	4	15
50–54	2	3	5
55–59	3	7	10
60–64	6	3	9
65–69	5	4	9
70–74	1	0	1
75–79	1	0	1
80–84	1	0	1
Total	221	222	443

1, they are dispersed widely in 1950 throughout South Dakota, North Dakota, Montana, Alberta and Manitoba.[4]

Our inquiries began with a brief questionnaire sent to all colonies during the months of December 1949 and January 1950, with a 100% response. This preliminary inquiry, made to plan the field-work, furnished, among other items, information about the total population, the number of persons over 65 years and under 15 years of age and the sex distribution. During the summers of 1950 and 1951 detailed demographic data were obtained for 71 of the 93 colonies, with about 80% of the population. The methods of inquiry included personal visits by the staff, intensive correspondence and in much of Manitoba, family

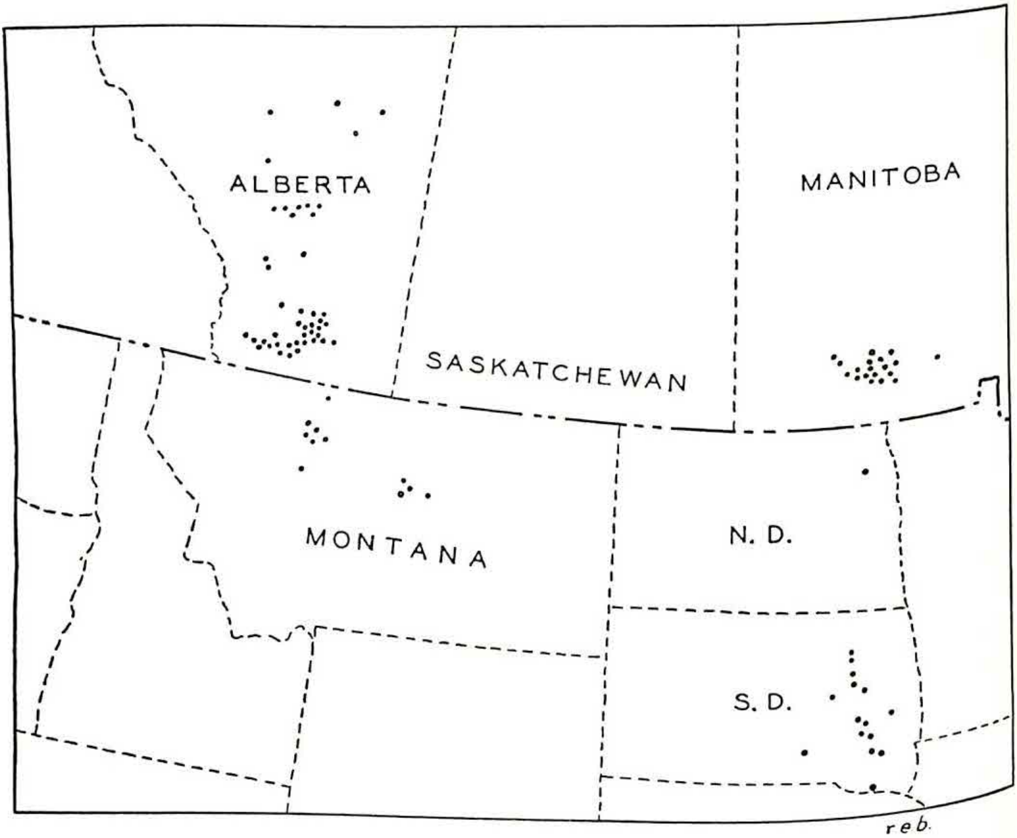

FIG. 1. ETHNIC HUTTERITE COLONIES IN NORTH AMERICA: 1950.

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[4] By March 1953, five additional colonies had been formed, two of them in the Canadian Province of Saskatchewan.

enumeration by a Hutterite leader.[5] Our data include records of 6,796 individuals, who were living on December 31, 1950. For these persons we have vital statistics broken down by families, colonies, and kinship groups including the following items of information:

a. Birthday or age by last birthday on December 31, 1950.
b. Birth-order within the family for all children ever born to parents living on December 31, 1950, including still-births.
c. Sex.
d. Marital Status.
e. Work or administrative position in the colony.
f. Death and sometimes cause of death of persons who died during the 10 previous years.
g. Residence (if known) of individuals not living in a Hutterite colony at the time of our enumeration.

The information on our sample was checked against many types of records. Some gaps and inconsistencies were found, but most of them could be cleared up through subsequent correspondence with Hutterite leaders. The selection of the 6,796 individuals was not random. It depended largely on the willingness of leaders to cooperate and the geographical ease of access of colonies to our staff. A review of the less detailed demographic data for which there is a 100% response shows the 80% sample for which we have detailed data to be representative of the entire population.

There were 8,542 ethnic Hutterites living on December 31, 1950. While the United States population increased 14.5% between 1940 and 1950, the Hutterites increased 52.1% in the same period, more than three times as rapidly. The Hutterite growth, as we shall demonstrate later, is largely a function of the excess of births over deaths. No other human population for which there are good vital statistics has shown a comparable steady growth over a prolonged period of time, except through migration.

The distribution of the 1950 population by age and sex is shown in table 3. It is more regular than it was in 1880. The three demographic features to which we called attention in our discussion of the 1880 findings are also found 70 years later:

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[5] Rev. Samuel Kleinsasser of the Sturgeon Creek Colony in Manitoba visited many Hutterite settlements in the province to take the family data needed for this study.

TABLE 3

Distribution of the Hutterite Population by Age and Sex on December 31, 1950

AGE	MALE	FEMALE	TOTAL
Under 1	175	179	354
1–4	698	680	1,378
5–9	722	646	1,368
10–14	595	629	1,224
15–19	434	474	908
20–24	330	337	667
25–29	298	304	602
30–34	231	231	462
35–39	189	213	402
40–44	165	120	285
45–49	125	111	236
50–54	91	91	182
55–59	74	69	143
60–64	46	40	86
65–69	39	25	64
70–74	22	29	51
75–79	5	6	11
80–84	5	3	8
85–89	3	1	4
90 and over	0	2	2
Unknown	34	72	106
Total	4,281	4,261	8,542

1. The number of males and females in 1950 was nearly equal (4,281 and 4,261).
2. Slightly over half of the population, 50.6%, was under 15 and 2.3% was over 65.
3. There were more males than females in the age groups over 40.

AGE AND SEX DISTRIBUTION

Age Distribution

In 1880, the population of the United States was predominantly youthful. Not only the Hutterites, but most American groups had a large proportion of infants and young children. This was the result of a combination of a high birth rate, a relatively low life-expectancy and the preponderance of young people among immigrants. During the following 70 years the age distribution of the American population changed. The proportion of older people increased steadily.

The Hutterites did not follow this trend. In 1950, even more than in 1880, they were a youthful group, as shown in table 4. They may hold a demographic " world record " for a relatively youthful age distribution.

TABLE 4

Age Distribution of Hutterites and Selected Populations (in per cent)[1]

	TOTAL	UNDER 5 YEARS	5 TO 19 YEARS	20 TO 44 YEARS	45 TO 64 YEARS	65 YEARS AND OVER
Hutterites (1950)	100	20	41	29	8	2
United States (1950)	100	11	24	37	20	8
Algeria (Moslems) (1948)	100	15	38	32	12	3
Jamaica (1948)	100	13	33	37	13	4
Israel (1948)	100	13	24	44	15	4

[1] United Nations Demographic Yearbook ('51).

Their age distribution has been quite stable through time. This can be shown through the application of the survivorship method to the 1950 age distribution to obtain the age distributions for the previous decades. The 1880 population was projected forward to 1910. The data are presented in figure 2, showing the population pyramids for decennial periods from 1880 to 1950.

Sex Distribution

There is nothing unusual in the overall Hutterite sex ratio. It has remained quite stable over the entire period. It was 99 in the 1880 census, 101 in the 1950 census and, by projection, 99 in 1940. As is usual in many human populations, there is a slight excess of males in the age group under 15. In the 5-9 year age group, there is an unusually high disproportion of males over females. The same irregularity can be observed in the rural farm population of the United States.[6] In

[6] The male death rate exceeds that of females when it is summed over the entire 0-14 age span (see table 17), but this sex difference is not consistent for the entire span. The female death rate of Hutterites from 1-4 is higher than that of males. The rates are reversed in the age groups of 5-9 and 10-14. These

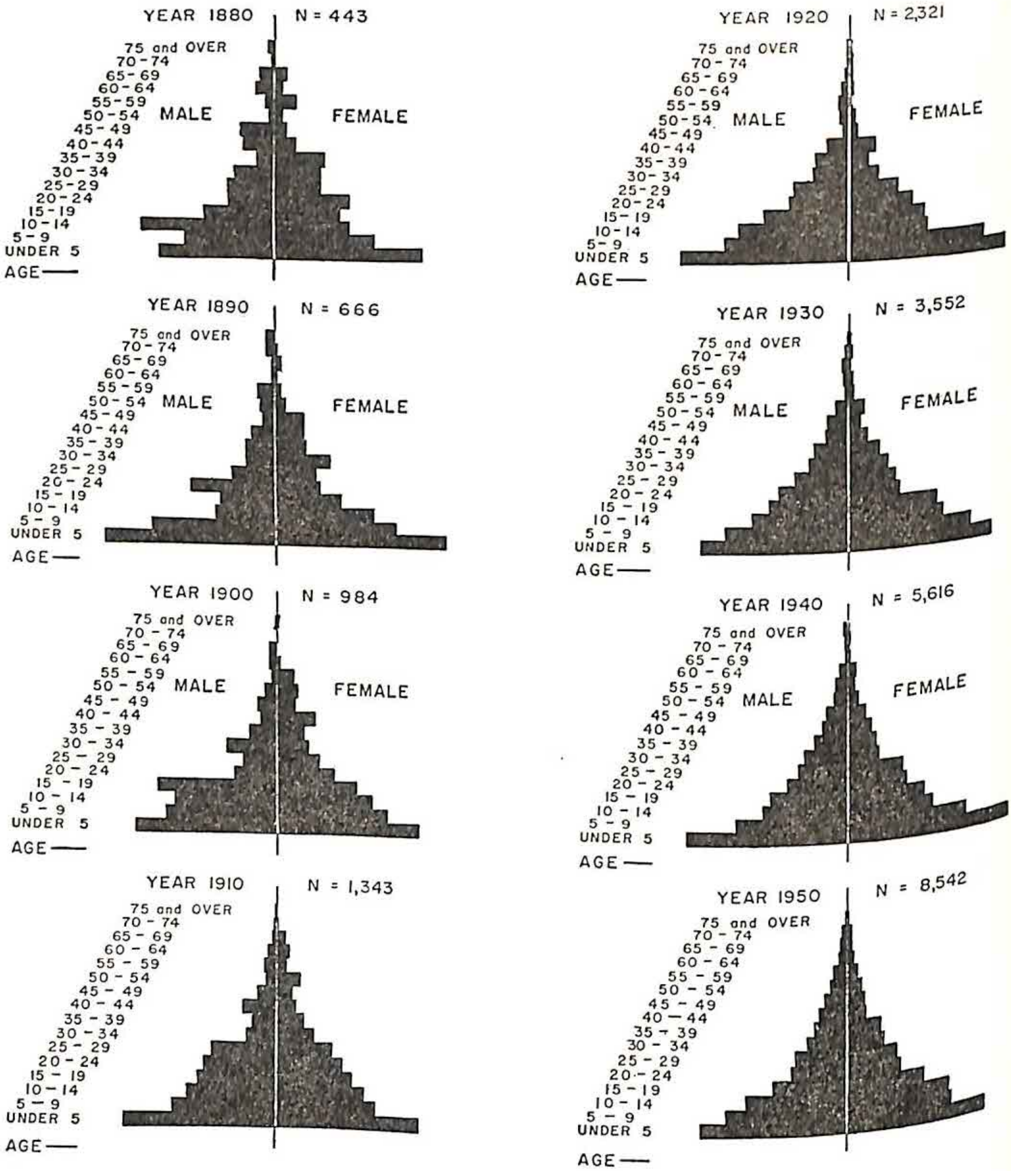

FIG. 2. POPULATION PYRAMIDS, ETHNIC HUTTERITES: 1880 to 1950.

most other populations the reverse conditions pertain. We have no explanation for this strange sex-ratio in the 5-9 year age group. It could be a sampling accident. However, a preliminary inspection of demographic data from other rural areas indicates that this phenomenon occurs elsewhere. Further study seems to be indicated to explore if there are biological or social forces which have gone unnoticed so far, which produce this high sex ratio in the 5-9 year age group of certain populations.

But it is very unusual to find a male predominance among the older age groups, as there is among Hutterites 40 years old and older. Hutterite men who live beyond 40 seem to have a greater life expectancy than women. This fact also makes sense in light of the finding that there were 72 men as against 61 women who had lost their spouse through death, although Hutterite husbands are on the average one and one-half years older than their wives.

There is good reason to assume that Hutterite males have a higher life-expectancy than females at all adult ages, even in the 15-39 and 70-74 age groups, when the number of women enumerated in 1950 was greater than the number of males. It is probable that there was an under-enumeration of males over 15 in some of the colonies, particularly those containing the 20% of the population for which complete family data could not be obtained. Males outnumbered females by a ratio of 13 to 1 among the Hutterites in 1950 who were known to have left their colony. These "deserters" are sometimes forgotten because their names were not always kept in the current records of their colony. Most of them were 15-19 years of age, with progressively declining numbers in the older age groups. Many of the youngsters return to the "fold" during their twenties, after having tried life on their own. The excess of females is greatest in those age groups in which males desert and becomes progressively less in the older age groups.

The finding that Hutterite men tend to outlive women might be a function of the large number of pregnancies experienced by the great majority of Hutterite wives. In the past, nearly all of their confinements were without the supervision of physicians. While Hutterite women

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rates are based on such small numbers of deaths that the variations would not necessarily be significant. However, they do fit with our data on the age distribution of the Hutterite population. The observance of the same irregularity in the American rural farm population indicates that the problem warrants more careful investigation.

do enjoy the help of self-trained midwives, some of whom have remarkable practical know-how, the cumulative effect of these numerous medically unattended pregnancies may be to shorten the length of life of women, who—in general—survive males in reproductively less active populations.

The Hutterites also demonstrate a demographic truism: A rapidly growing population is very youthful. About 51% of the 1950 population was under 15 years of age. Two percent were over 65 years of age. Persons in these age groups cannot be expected to be fully productive economically or active in the management of the group's affairs. If we add to this finding the fact that the majority of female adults were preoccupied with the care of their large families, it becomes very clear that a relatively small number of Hutterite male adults must provide economic support for their rapidly growing group. This might be difficult if it were not for the Hutterite values which emphasize a sharing of all property and the spiritual virtue of living at an austerity standard. In most cultural settings, a rapid population growth like that experienced by the Hutterites would tend to be checked by difficulties of providing the offspring of most families with the essentials of food, clothing, shelter and medical care. The Hutterite economy and value system are uniquely designed to deal with this problem. Even an inefficient or ill father can support a large family, while the more capable members of the group forego the economic benefits which would accrue to them if they were to be paid wages for their labor based on their importance to the group effort. They do this out of religious conviction and ethnic loyalty. It is doubtful that the Hutterite reproductive record could be maintained were competing American materialistic and secular values to bring about any major modification in their communal economic structure.

REPRODUCTION

Human Fecundity and Fertility

Fecundity, the physiological capacity for reproduction, is fairly well known for many animal species. There are no equally reliable data for *Homo sapiens*. Reproduction in human beings is not purely instinctive behavior expressed during a mating season or a period of "heat." It is a socio-biological process. It involves some of the most strongly held cultural values and taboos. No human group which has been available for study to demographers over a long period of time have had sex and marriage practices which encouraged reproduction at a high enough level to come close to their possible biological maximum. But it would be useful if an estimate of this theoretical maximum could be made.

The concept of *population fecundity*, to be used here, will refer to the number of living offspring produced by a group of women in their total reproductive life time. This definition differs somewhat from the conventional meaning attached to this term by biologists and students of population, but it permits us to answer the really crucial question: How many children can a group of human beings have if they reproduce up to the limit of their biological capacity and live through their entire period of potential fertility? This concept also facilitates the answer of the corollary question: How many children are *not* produced by a group of human beings because some of their cultural values, customs or habits interfere with biologically possible reproduction?

The vital statistics of the Hutterites can serve as a basis for making such estimates. Fertility will be analyzed through a number of measures in common use by demographers to permit a cross-cultural comparison of relevant populations, including the following:

1. The crude Birth Rate
2. The Fertility Ratio
3. Age Specific Birth Rates
4. Completed Family Size
5. Nuptial Age Specific Birth Rates

The Crude Birth Rate

The crude birth rate of the sect, the number of births per 1,000 population was 45.9 during the 5 year period of 1946 through 1950. This rate is based on complete fertility data for the 80% sample.

This crude birth rate of nearly 46 per 1,000 is high (see table 5) but not the highest in the world. However, it is well known that crude birth rates are not an accurate measure of fertility since they are not corrected for the great variations in the age and sex distribution of the different populations. They are, as their name indicates, only a *crude* measure of fertility.

The Fertility Ratio

The fertility ratio, the number of children under 5 years of age per 100 women of age 15 to 49, is a somewhat more accurate measure of fertility than the crude birth rate. But it has somewhat less comparability. It cannot be obtained for some populations because its calculation requires data on the detailed age and sex distribution of the population.

Among the Hutterites, the 1950 fertility ratio was 96.3 per hundred women. It is greater than that of any other human population. It is more than twice the total United States fertility ratio in 1950 and 53% higher than that of Algerian Moslems in 1948, the highest fertility ratio reported in the 1950 United Nations Demographic Yearbook. The cross-cultural comparisons are given in table 6.

TABLE 5

Crude Birth Rates of the Hutterites and Selected Populations[1]

POPULATION	CRUDE BIRTH RATE
Hutterites (1948)	45.9
Algeria (Moslems) (1949)	34.1
Jamaica (1948)	30.9
Israel (1948)	26.8
United States (1948)	24.2

[1] United Nations Demographic Yearbook ('51).

TABLE 6

Fertility Ratios of the Hutterites and Selected Populations[1]

POPULATION	CHILDREN UNDER 5 YEARS OF AGE, PER 100 FEMALES 15 TO 49
Hutterites (1948)	96.3
Algeria (Moslems) (1948)	63.1
Jamaica (1949)	49.5
Israel (1948)	45.8
United States (1950)	42.3

[1] United Nations Demographic Yearbook ('51).

The fertility ratio is an improvement over crude birth rates, but it also has some shortcomings as a measure of fertility. It makes only a rough correction for variations in the age distribution of different populations. It also takes no account of marital status. It does reflect mortality, however.

Age Specific Birth Rates

Age specific birth rates are more accurate measures of fertility because they take more complete account of the variations in the age distribution of a population. We will employ two measures here:

1. The age specific fertility rate. It is the number of births per year to 1,000 women in a specific age group including both *married* and *unmarried* women.
2. The age specific nuptial fertility rate. It is the number of births per year to 1,000 *married* women in a specific age group.

In table 7 the age specific fertility rates of the Hutterite population are given, together with the highest observed rates reported in the 1950 United Nations Demographic Yearbook. This cross-cultural comparison shows Hutterite females to have a record fertility in all but the 15-19 year old age groups.

TABLE 7

Age Specific Fertility Rates of the Ethnic Hutterite Population 1946–1950 and of Selected Countries

AGE GROUP [1]	TOTAL HUTTERITE WOMEN	NUMBER HUTTERITE WOMEN MARRIED	NUMBER OF BIRTHS 1946-1950	ANNUAL AGE SPECIFIC NUPTIAL FERTILITY RATE	ANNUAL AGE SPECIFIC FERTILITY RATE	HIGHEST OBSERVED AGE SPECIFIC FERTILITY RATE CIRCA 1948 [2]
15–19	301	39	18	92.31	11.96	103.1 (Jamaica)
20–24	252	173	291	336.42	230.95	227.3 (Jamaica)
25–29	220	169	421	498.22	382.73	268.4 (Japan)
30–34	180	159	352	442.76	391.11	233.3 (Japan)
35–39	130	121	224	370.24	344.61	156.4 (Japan)
40–44	96	93	100	215.06	208.34	59.4 (Netherlands)
45–49	76	74	16	43.24	42.11	6.8 (Jamaica)
Total	1,255	828	1,422			

[1] The ages of Hutterite women are listed as of *June 30, 1948,* the center point of five year period 1946-1950. The data are from our 80% sample for which complete fertility records were obtained.

[2] United Nations Demographic Yearbook ('49-'50).

The relatively low fertility of young Hutterite girls reflects their custom of marrying only after adult baptism has taken place. The median age of marriage in 1950 for Hutterite women was 22.0. For men the corresponding median was 23.5. Among the 301 girls who were between the age 15-19, only 20, or about 7% were married before they were 19.

None were married before they reached their sixteenth birthday. The age specific fertility rate of 12.0 per 1,000 for this age group is quite low, much lower than the 79.8 per 1,000 of the U. S. population. This clearly indicates the importance of Hutterite social taboos in inhibiting reproduction during the late adolescent years.

TABLE 8

Number and Percentage of Persons over 30 Never Married In 70 Hutterite Colonies in 1950 [1]

MALE

AGE GROUP	TOTAL POPULATION	TOTAL UNMARRIED	PER CENT UNMARRIED IN AGE GROUP	SEX RATIO
30–34	181	7	3.9	1.00
35–39	148	4	2.7	.89
40–44	131	1	0.8	1.38
45 & over	323	3	0.6	1.09
Total	783	15	1.9	1.05

FEMALE

AGE GROUP	TOTAL POPULATION	TOTAL UNMARRIED	PER CENT UNMARRIED IN AGE GROUP	SEX RATIO
30–34	184	27	14.1	1.00
35–39	166	17	3.6	.89
40–44	94	4	4.3	1.38
45 & over	299	4	1.3	1.09
Total	743	52	5.4	1.05

[1] Non ethnic Hutterites who became converted and their children are excluded from this tabulation, which is based on 78.9% of the total ethnic Hutterite population. Excluded also are 9 persons age unknown, and 106 male and 8 female Hutterites known to have left Hutterite colonies before December 31, 1950, who may have been alive at that time.

The peak of nuptial fertility is in the 25-29 year old group. The rate during this period is 498 per 1,000. In other words, women in this age group average one birth every two years. The high fertility rates of the Hutterites after the age of 20 is a reflection of their cultural encouragement of reproduction. Few adults are single by the time they reach their thirtieth birthday. As table 8 shows, less than 2% of the males 30 years old and older were unmarried. Among women failure to marry was more common. Slightly over 5% of these over 30 were spinsters. In a population which is rapidly increasing there tends to be a surplus of women if men marry girls younger than themselves. Yet it is doubtful that many Hutterite spinsters are condemned to their state of single blessedness simply by an inability to find a marriage partner. There are too many volunteer match-makers among friends and relatives to permit that. Health reasons, a desire to remain at home with parents, and personality factors were found to be involved in the few instances when girls chose to remain single. The surplus of females among Hutterites is gradually absorbed, partly because men tend to remarry, while women rarely do. Fifty-five percent of the 72 widowers remarried, as against 5% of the 61 widows. By the time Hutterites reach their forty-fifth birthday, only about one percent of either sex have never been married. The high marriage rate of Hutterites is mirrored in the tendency for age specific and nuptial fertility rates to converge as the age of women increases. In the 40-44 and 45-49 year age groups, when all but 4.3 and 1.3% respectively of the women are married, the two age specific rates are fairly close to each other.

Hutterite couples are rarely separated after marriage. In the history of the group since 1875 there has been only one divorce and only 4 desertions. We know of one other case where husband and wife separated temporarily to live in different colonies. There may have been a few other such cases, although if the separation had extended over a span of several years the cases could hardly have escaped the attention of our field staff. Family break-up through death has been much more common. There were 133 persons in the 80% sample who had lost their consorts through death, about 6% of all married males and females.

Regularity in exposure to pregnancy appears to be accepted as normal in marriage, but sex relations are severely frowned upon during the pre-marital period.[7] There are, no doubt, considerable variations in sexual activity among families within the culture but our study did not attempt to investigate this topic. There are no general customs which inhibit sex relations of married persons, except for a few weeks before parturition and for about 6 weeks afterwards. In general, our interview data suggest that after the marriage vows are taken, women are regularly exposed to the chance of fertilization.

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[7] Illegitimate births are very rare. We have some evidence that 10 babies may have been born outside of wedlock since 1875. While it is not possible for us to give a precise rate for this phenomenon, we estimate that illegitimate births account for less than two tenths of one percent of all births since 1875.

The magnitude of the age specific fertility rates of the sect can be summarized by the comparisons made in table 9. They show:

TABLE 9

Actual and Expected Number of Births of the Ethnic Hutterite Population Calculated by U. S. and Highest Recorded Age Specific Birth Rates in 1950 [1]

AGE GROUP	NUMBER OF HUTTERITE WOMEN	UNITED STATES RATE	HIGHEST RECORDED AGE SPECIFIC	EXPECTED NUMBER OF BIRTHS BY U. S. RATES	EXPECTED NUMBER OF BIRTHS BY RATE OF HIGHEST COUNTRY	ACTUAL NUMBER OF BIRTHS
15–19	301	79.8	103.1 (Jamaica)	12	103	18
20–24	252	193.2	227.3 (Jamaica)	243	286	291
25–29	220	160.6	268.4 (Japan)	177	295	421
30–34	180	100.5	233.3 (Japan)	90	210	352
35–39	130	53.2	156.4 (Japan)	35	102	224
40–44	96	15.2	59.4 (Netherlands)	7	29	100
45–49	76	1.2	6.8 (Jamaica)	1	3	16
Total	1,255			565	1,028	1,422

[1] United Nations Demographic Yearbook ('51).

1. Only 39% as many Hutterite babies would have been born if the Hutterites in 1950 had had age specific birth rates similar to those of the United States in general.
2. Only 62% of the Hutterite babies would have been born if the Hutterites in 1950 had had age specific birth rates similar to those of the country listed in the 1950 United Nations Demographic Yearbook as having the highest recorded birth rate in each 5-year group.

Variations of Birth Rates

The remarkable fertility of the sect now may be regarded as established. One further question remains before making an estimate of fecundity. A considerable portion of population theory has been concerned with the question whether reproductive capacity changes, presumably lessens, as a population matures. Are the Hutterites following other groups in showing a decrease in birth as they accept modern technological changes and come into more contact with the larger American Society?

Completed Family Size

Completed family size, the number of children ever born to a woman before reaching the age of 45,[8] can be used as a measure of fertility trends. There seems to have been a slight increase in family size since 1880 (table 10). The 166 younger women who were between 45 and 54 in 1950 had an average number of 10.6 live births. The 162 who were between 55 and 74 years of age had an average of 9.9 children.[9] It is possible that the greater completed family size of younger women is due to the improvement of medical care in recent decades, reducing the number of still-born and strengthening the general health of mothers. The inverse relationship of women in 1950 and completed family size is a further clue to the validity of the assumption that a large number of pregnancies has an adverse effect on longevity. For example, the fact that the 12 women who were 75 years old and older and alive in 1950 had only an average of 7.5 children (a suspiciously low number for

TABLE 10

Number of Children Ever Born to Married Ethnic Hutterite Women 45 Years of Age and Over, 1950

Age Group	NUMBER OF CHILDREN 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total	Median
45-49.......	2	0	3	2	2	2	7	10	4	11	10	9	13	6	7	6	0	94	10.9
50-54.......	1	1	1	2	2	5	3	8	9	5	4	11	9	3	2	3	3	72	10.3
55-59.......	4	1	2	2	3	4	6	3	4	9	6	12	4	1	3	0	1	65	9.9
60-64.......	2	0	1	0	1	2	1	1	6	6	8	3	1	2	2	2	0	38	10.3
65-69.....	0	0	1	3	0	0	1	0	7	7	2	2	1	2	1	3	0	30	9.9
70-74.......	1	2	1	0	1	0	1	1	1	3	9	4	1	2	1	1	0	29	9.2
75-79.......	0	0	0	0	1	1	0	3	0	0	1	0	0	0	1	0	0	7	....
80-85.......	0	0	0	1	0	0	1	0	0	1	0	1	0	0	1	0	0	5	....
Total.......	10	4	9	10	10	14	20	25	31	42	40	42	29	16	18	15	4	340	10.4

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[8] It is conventional to calculate completed family size on the basis of the number of children born to women between the age of 15 and 45. Actually, this convention neglects the fact that some births take place after 45 years of age.

[9] The completed family size of the Hutterites is similar to that recently reported by Keyfitz ('53) for rural French Canadians.

Hutterites!) might be due to the failure of women with very large families to survive to be counted in our 1950 census. Finally, the possibility cannot be ruled out that older women failed to record some of their children who died young or left the colony a long time ago. However, the internal consistency of our data makes it appear doubtful that such forgetfulness was widespread.

No significant differences in completed family size were found to be associated with kinship group membership or social position. The median family size of 118 wives of preachers, business managers and other community leaders 45 years old or older, was 10.2 children. For wives of regular members, without any position of formal leadership in 1950, the median family size was 10.4 children. In both groups, about 5% of the babies were reported to have died before reaching their first birthday. While most populations vary greatly in socio-cultural factors associated with fertility, such as education, occupation, income and status, Hutterites do not. They are not made out of one mold, but their culture is characterized by a high degree of homogeneity. There are virtually no class distinctions. All people in a colony have the same level of living. There are variations in social prestige, which are largely a function of sex, age, intelligence and religious grace. But these variations do not seem to affect fertility.

Nuptial Age Specific Birth Rates

A comparison of the annual nuptial age specific birth rates for the periods 1926-1930, 1936-1940 and 1946-1950 is shown in table 11. Many of the variations in the rates of 5 year age groups throughout this period are not significant. They are based on small numbers. The following trends may be observed:

1. Hutterite fertility has been generally high throughout the 30 year period.

2. Nuptial fertility rates have decreased progressively for the 15-19 and 20-24 year groups. The trend is particularly marked for the 15-19 year age group. Their nuptial rates have grown considerably smaller. World War II contributed greatly to pushing the rate for 1946-1950 down below the level it might otherwise have maintained. The differences in nuptial rates of 20-24 year olds between 1936-1940 and 1946-1950 disappear when corrected for the number of years women were actually married during these 5 year periods. Many young Hutterite males were

TABLE 11

Age Specific Fertility Rates for the Ethnic Hutterites
1926–1930, 1936–1940, 1946–1950

AGE GROUP	TOTAL HUTTERITE WOMEN	MARRIED HUTTERITE WOMEN	PERCENT MARRIED	NUMBER OF BIRTHS	ANNUAL AGE SPECIFIC BIRTH RATE	ANNUAL AGE SPECIFIC NUPTIAL BIRTH RATE
1926–1930						
15–19	130	6	4.6	11	16.9	366.7
20–24	103	68	66.0	138	268.0	405.9
25–29	92	85	92.4	192	417.4	451.8
30–34	69	66	95.7	137	397.1	415.2
35–39	40	40	100.0	71	355.0	355.0
40–44	36	36	100.0	43	238.9	238.9
45–49	34	34	100.0	4	23.5	23.5
Total	504	335	66.5	596	236.5	355.8
1936–1940 [1]						
15–19	198	11	5.6	13	13.1	236.4
20–24	176	117	66.5	228	259.1	389.7
25–29	129	120	93.0	300	465.6	500.8
30–34	98	97	99.0	224	461.9	466.7
35–39	85	84	98.8	183	430.6	435.7
40–44	68	65	95.6	69	202.9	212.3
45–49	42	42	100.0	10	47.6	47.6
Total	796	536	67.3	1,027	258.0	383.2
1946–1950						
15–19	301	39	13.0	18	12.0	92.3
20–24	252	173	68.7	291	231.0	336.4
25–29	220	169	76.8	421	382.7	498.2
30–34	180	159	88.3	352	391.1	442.8
35–39	130	121	93.1	224	344.6	370.2
40–44	96	93	96.9	100	208.3	215.1
45–49	76	74	97.4	16	42.1	43.2
Total	1,255	828	66.0	1,422	226.6	343.5

[1] Thirteen births, age of mother unknown have been allocated.

absent from their home during several years in which they served either in a camp for Conscientious Objectors or in the Armed Forces. This delayed many marriages. When corrected for this there was a little change in fertility as is shown in table 12.

TABLE 12

Number of Children per Year of Marriage Born to Women Age 20–24 in 1940 and 1950

	1940				1950			
AGE	NUMBER OF WOMEN	TOTAL YEARS OF MARRIAGE	NUMBER OF CHILDREN	RATIO	NUMBER OF WOMEN	TOTAL YEARS OF MARRIAGE	NUMBER OF CHILDREN	RATIO
20	5	2.5	2	.80	7	7.5	3	.40
21	17	17.0	9	.53	19	20.5	13	.63
22	17	30.5	24	.79	24	38.5	20	.52
23	23	52.0	32	.62	35	74.5	54	.72
24	26	68.5	45	.66	41	79.0	65	.82
Total 20–24	88	170.5	112	.66	126	220.0	155	.70

3. The peak of nuptial fertility in every decade is in the 25-29 age group. Married women have about one child every two years during that time.

4. Nuptial fertility for women in the 35-39 year age group was highest in 1936-1940 and dropped off markedly in 1946-1950. This finding suggests that birth control practices might be beginning to make inroads, although it might merely be a temporary fluctuation.

5. The Hutterite nuptial fertility of 1936-1940 did not parallel the trends of the American population in general. Birth control practices, the economic after-effects of the depression and a related negative evaluation of child-bearing, important factors in lowering American rates during that period, did not seem to affect the Hutterites.

Hutterite Fecundity

We are now ready to make an estimate of the fecundity of the Hutterite population from its fertility data. It is assumed that Hutterite fertility approximates fecundity except in the early years of the reproductive period.

The estimates are based on the concept of probability of conception of a live child[10] by a married woman living with her spouse, at a given age, in a given year. Each such Hutterite woman (living or dead) was carried through her fertility period beginning with the year of her marriage and ending with her fifty-first year. If she was less than 51 years old in 1950, her fertility experience to that date was tabulated. For every year of exposure to pregnancy a tabulation was made as to whether or not a conception which resulted in a live birth took place. The results are shown in table 13. The probability of having a live birth during the middle year of each 5 year age group is indicated in figure 3. Over the entire reproductive span, the summation probabilities yields a figure of nearly 12 live births per woman, married at the age of 18, and living with her husband through her fifty-first year of life.

We have no estimates of fertility for the ages under 18, when few Hutterites get married. The peak seems to be in the twentieth year of life, when 61.1% of the married women had a live birth. In the years following this peak, fertility declines progressively, but slowly. Not until about the fortieth year of age does the rate of decline become pronounced. Fertility approaches zero at the age of 49. The decline reflects a decrease in fecundity. The extent to which this is the case is not certain because the frequency of sexual relations in marriage also tends to decline with age. (Kinsey, et al., '48 : 252 and '53 : 348-354.) It appears that the fecundity of human beings is far more stable than has been generally assumed. Its decline with age is probably even more gradual than is suggested in figure 3.

On the surface, the finding that the peak of population fecundity is in the twentieth year of life contradicts our prior observation that nuptial fertility rates were highest for women in the 25-29 year age groups. This artifact is the result of the process of combining the data in 5-year age groups. Women in the 20-24 year age group were actually exposed to motherhood for only about 1¾ out of the 5 years; those in the 25-29 year period were exposed for about 4 years. Hutterite women are more fertile in their early twenties, but not enough of them are married to yield 5-year grouped nuptial fertility rates to indicate this fact. This finding is a good illustration of the limitation of grouped nuptial fertility rates as measures of population fertility.

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[10] Still births are excluded. The elimination of abortions, miscarriages and still births, and consequently the viewing of fecundity in terms of live births only, sharpens and clarifies the concept although this operational definition of fecundity is not in accord with the usual meaning of the term.

TABLE 13

Probability of Having a Live Birth at a Given Age, by Decade of First Marriage, Ethnic Hutterite Women

Age	Before 1921				1921-1930				1931-1940				1941-1950				Total			
	Total	Births	No Births	Probability	Total	Births	No Births	Probability	Total	Births	No Births	Probability	Total	Births	No Births	Probability	Total	Births	No Births	Probability
15	...	...	...	....	...	...	...	....	...	...	...	....	...	...	...	....	...	...	...	....
16	...	...	...	....	...	...	...	....	1	1	...	....	...	...	...	....	1	1	...	....
17	...	...	...	....	2	...	2	....	1	...	1	....	3	1	2	....	6	1	5	....
18	15	7	8	.467	10	4	6	.400	6	5	1	.833	8	5	3	....	39	21	18	.538
19	64	34	30	.531	41	29	12	.707	21	11	10	.524	30	19	11	.633	156	93	63	.596
20	116	64	52	.552	82	47	35	.573	88	67	21	.761	82	47	35	.573	368	225	143	.611
21	138	64	74	.464	119	74	45	.622	142	85	57	.599	132	92	40	.697	531	315	216	.593
22	161	73	88	.453	133	72	61	.541	183	107	76	.585	174	121	53	.695	651	373	278	.573
23	171	82	89	.479	151	76	75	.503	203	103	100	.507	184	106	78	.576	709	367	342	.518
24	172	77	95	.448	152	81	71	.533	271	132	139	.487	165	104	61	.630	760	394	366	.518
25	174	86	88	.494	156	77	79	.494	233	125	108	.536	152	96	56	.632	715	384	331	.537
26	174	81	93	.466	165	89	76	.539	232	117	115	.504	139	81	58	.583	710	368	342	.518
27	176	77	99	.438	164	83	81	.506	238	133	105	.559	108	69	39	.639	686	362	324	.528
28	175	69	106	.394	160	82	78	.513	235	106	129	.451	80	35	45	.438	650	292	358	.449
29	176	82	94	.466	162	74	88	.457	231	130	101	.563	60	38	22	.633	629	324	305	.515
30	171	64	107	.374	165	73	92	.442	233	108	125	.464	38	16	22	.421	607	261	346	.430
31	169	82	87	.485	163	75	88	.460	220	117	103	.532	26	15	11	.577	578	289	289	.500
32	169	68	101	.402	165	68	97	.412	199	96	103	.482	17	11	6	.647	550	243	307	.442
33	176	75	101	.426	168	82	86	.488	179	73	106	.408	10	3	7	.300	533	233	300	.437
34	164	72	92	.439	163	70	93	.429	155	67	88	.432	6	4	2	.667	488	213	275	.437
35	169	65	104	.385	163	86	77	.528	136	60	76	.441	7	4	3	....	475	215	260	.453
36	168	65	103	.387	162	56	106	.346	98	43	55	.439	6	3	3	....	434	167	267	.385
37	164	63	101	.384	162	65	97	.401	75	29	46	.387	6	3	3	....	407	160	247	.393
38	167	60	107	.359	159	71	88	.447	55	20	35	.364	6	3	3	....	387	154	233	.398
39	159	56	103	.352	147	44	103	.299	41	18	23	.439	5	1	4	....	352	119	233	.338
40	159	47	112	.296	138	52	86	.377	28	4	24	.143	3	1	2	....	328	104	224	.317
41	155	45	110	.290	123	28	95	.228	22	10	12	.454	2	0	2	....	302	83	219	.275
42	149	27	122	.181	118	29	89	.246	18	4	14	.222	2	1	1	....	287	61	226	.213
43	147	25	122	.170	96	15	81	.156	12	1	11	.083	...	...	...	....	255	41	214	.161
44	146	11	135	.075	88	9	79	.102	12	1	11	.083	...	...	...	....	246	21	225	.085
45	143	16	127	.112	73	7	66	.096	12	1	11	....	...	...	...	....	228	24	204	.105
46	141	3	138	.021	56	1	55	....	8	0	8	....	...	...	...	....	205	4	201	.020
47	141	1	140	....	47	2	45	....	9	1	8	....	...	...	...	....	197	4	193	.020
48	139	0	139	.000	36	4	32	.111	6	0	6	....	...	...	...	....	181	4	177	.020
49	136	0	136	.000	25	1	24	....	6	0	6	....	...	...	...	....	167	1	166	.006
50	129	0	129	.000	18	1	17	.056	4	0	4	.000	...	...	...	....	151	1	150	.007
51	125	2	123	.016	16	0	16	.000	4	0	4	.000	...	...	...	....	145	2	143	.013

Fertility has not remained stable over the period under review. As shown in table 13 it has increased with great consistency in each age group with each succeeding 10 year period. There has been a rise in the number of live births to women during the entire reproductive span.

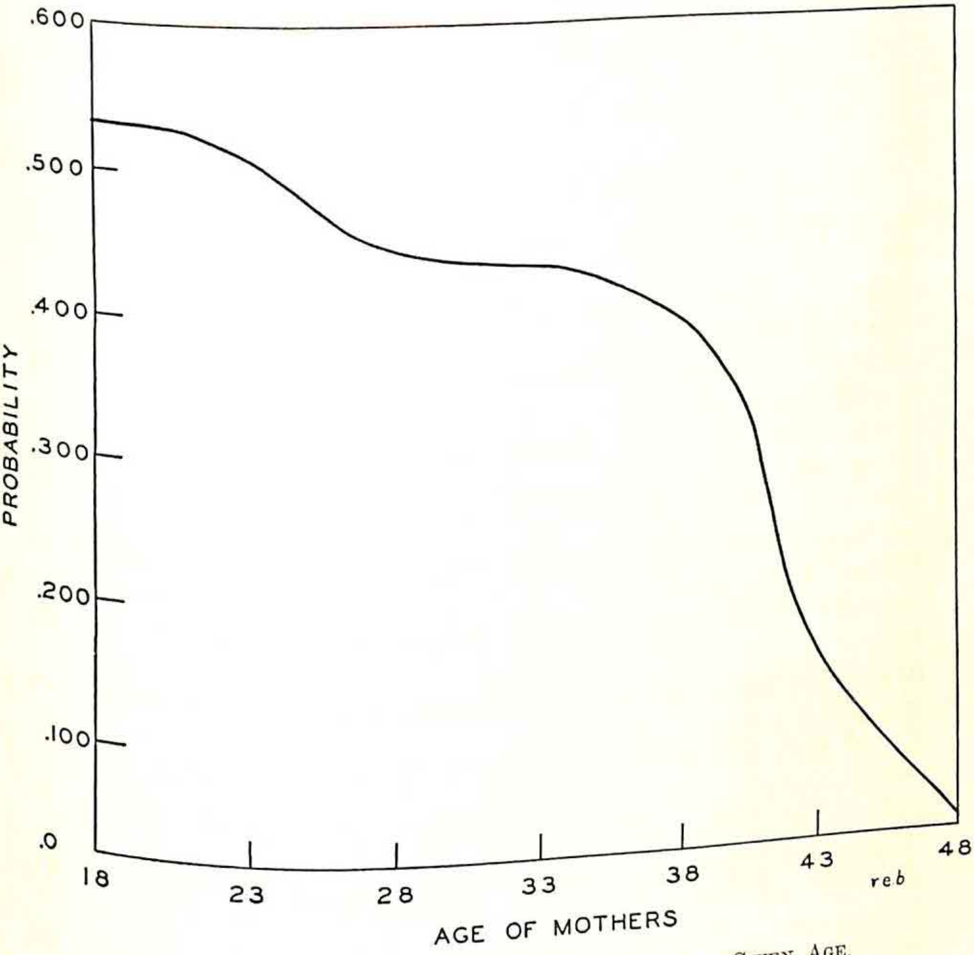

FIG. 3. PROBABILITY OF HAVING A LIVE BIRTH AT A GIVEN AGE, ETHNIC HUTTERITE WOMEN.

Women married at 18 before 1921 who remained married through their fifty-first year of life, had 10.8 live children. The number increased to 12.0 for women married between 1921 and 1930, and 12.3 for women married between 1931 and 1940. The same steady increase can be observed if we sum only the number of live children through the thirty-fifth year of life. These data are more reliable because they are based on larger numbers in each age group. For women married before 1921 the number of live children was 7.8 for married women 18-34 years of age. The equivalent numbers were 8.6 for women married in the decade 1921-1930, 9.2 for women married in the decade 1931-1940 and 9.3 for women married in the decade 1941-1950. Split halves of the data matched almost perfectly so as to give considerably more confidence in the reliability. It should be noted further that this same general trend was found in the data on completed family size (see table 10).

A number of factors could account for this trend. One is that the longer ago a birth occurred, the greater tendency for women to forget to report it. However, it seems unlikely that this could account for the extremely consistent rise in fecundity, particularly in view of the Hutterite emphasis on keeping family records. A more likely factor is the increasingly good health of Hutterite women, resulting in a decrease in abortions, miscarriages, and stillbirths with a reciprocal rise in successful deliveries. It may also reflect an increase in the number of conceptions. The previously reported drop in the 1946-1950 age specific birth rates of women 35-39 is not apparent in the fecundity data. The two measures were calculated on the basis of the birth performance of different groupings of women. A short-term trend in age-specific birth rates of a single age group could be masked by the methods of classifying women by their decade of marriage used in fecundity calculations. However, if this trend continues, it will probably show up in the next decade as a decrease in fecundity.

The maximum population fecundity of the Hutterites can be estimated by making allowance for the number of children who might be born, if Hutterite customs encouraged women to marry younger. Fecundity at these early ages (13-17) cannot be estimated easily because of the phenomenon of adolescent sterility. On the basis of information from primitive cultures, some anthropologists believe that girls are not very fertile during their first few post-pubertal years. Relatively few girls are capable of reproduction before 15 years of age and even then their reproductive capacity is not as great as it will be later (Ford and Beach, '51). Accepting this theory, at least for the purpose of making an estimate of maximum fecundity, one to two and a half children might be added to the totals. The maximum fecundity of the Hutterite population would then range somewhere between 12 and 14 live births, for women reproducing at rates of the 1931-1940 decade. The actual completed family size of Hutterite women is about one to three children less than this maximum theoretical number of births because most Hutterite women marry after reaching the age of 20 and some lose husbands before they reach the end of their reproductive cycle.

Number of Children Still Possible After Any Given Age

Unless the Hutterites are genetically unusual, their population fecundity can be used to estimate the number of live children women can conceive after any given age. It should be noted that numbers cannot be applied to an individual case. The data are shown in table 14.

TABLE 14

Number of Children Still Possible per Woman After Any Given Age by Five Year Age Groups, for the Ethnic Hutterite Women Living on December 31, 1950

AGE	NUMBER OF LIVE BIRTHS STILL POSSIBLE
50 and over	.02
45	.19
40	1.24
35	3.21
30	5.46
25	8.00
20	10.82
15	11.95–13.85[1]

[1] No data were available for the 15th, 16th and 17th years. Our estimates have to be given as a range because we do not know the fecundity during these years. The minimum estimate assumes complete adolescent sterility below the 18th year, and the maximum estimate is based on a probability of having a child during the 15th through the 17th years as great as during the 18th and 19th years. The most likely estimate lies somewhere between these extremes, about 13 children.

These numbers underestimate the chances of giving birth of women who have recently begun their reproductive cycle. As we have mentioned previously, and have shown in table 13, the fertility of women married during the decade of 1941-1950 is considerably above that of the average of all Hutterite women living in 1950, whose pregnancy experience was used to make these expectancy estimates, probably because they get better food and medical care. If the trend toward higher fecundity continues, the probable number of live births to the recently married women who enjoy the most up to date sanitary, nutrition and health standards, will be even higher.

Is Hutterite Fecundity Unusually High?

The question whether Hutterites are more fecund than the general American population cannot be answered conclusively. In lower organisms, as Pearl ('25; '39) shows, great hereditary differences in reproductive capacity are found. In most human groups, such biological questions cannot be readily investigated. The Hutterites may be an exception to this rule. With their cooperation it would be possible to go beyond our present data to investigate familial (genetic), constitutional, psychological, social and cultural variables which affect their high birth rate. Such a study is being planned for the near future. In the meanwhile, some of the relevant facts related to Hutterite fecundity should be noted.

1. *Moderate Total Family Size*

There are no Hutterite females with more than 16 live births. Some might have had more, had they married earlier. But none come close to matching some of the unusually high reproductive histories reported by Pearl ('25; '39) and others, as for example the wife of a poor Viennese linen-weaver, who had 32 children, all but 4 of whom were born alive.

2. *Normal Rate of Twinning*

Hutterites have only the usual proportion of multiple births. There were 15 twin births out of a total of 1,422 births recorded during 1946-1950. This ratio of 1 per 95 is within the range of the frequency of multiple births in the United States, which is 1 per 86 (Strandskov '45).

3. *Reproductive Efficiency*

The human ova and spermatozoa have a brief life-span. The period within a woman's monthly cycle during which conception can take place has been estimated to be "a matter of hours, certainly no longer than a day." (Greenhill, '49). Raymond Pearl ('39) reported an average of 244 potentially effective copulations per live birth in women of age 20-29, the age span when fertility is relatively high. Pearl's findings were based on a sample of 184 white married women in Baltimore in whose marital experience no contraceptive effort whatever had been made.

Married Hutterites appear to have a much greater reproductive efficiency than these Baltimore women. They had an overall average of not quite twice as many children during the 10 year period, 5.36 as against 2.8. They had only slightly more than 13 ovulation cycles, with a maximum of 306 days,[11] in which to conceive each *live* birth. It must be emphasized that these are maximum estimates. They make no allowance for miscarriages, illness and normal separation of husband and wife because of travel. The actual number of ovulation cycles and days during which Hutterite women could have been exposed to reproductively effective copulation is much smaller.

The average of 244 copulations estimated by Pearl to have been necessary to produce each live child in his sample of couples appears to be excessively high. Our study made no attempt to obtain information on the sexual life of the Hutterites, but Kinsey, Pomeroy and Martin found that the frequency of marital relations was "consistently effected by the degree of church affiliation. In practically every instance the religiously active groups engage in marital intercourse less frequently than religiously inactive groups." (Kinsey, Pomeroy and Martin, '48: 482.) Hutterites in general are more religious than most of the persons interviewed by Kinsey and his team and classified by them as "actively religious." If we estimate Hutterite sex relations in the 20-29 year age group to average 2½ times per week, the approximate mean frequency reported in the Kinsey report for actively religious protestants, Hutterite women could have experienced only 108 copulations for each live birth. If an allowance is made for a reduction of this number because of illness or separation because of travel of one or both of the spouses, the Hutterites would appear to be more than twice as efficient reproductively as the couples studied by Raymond Pearl. The latter probably were relatively infertile. Considering their claim that no contraceptive effort whatever was made in their entire marital experience it seems strange that they had only 2.8 live births during the age period of 20-29 and 4.9 children over their entire reproductive span. If one were to assume that the fecundity of the Hutterite population does not differ significantly from that of other human groups who live under civilized standards of nutrition and health care, and with not too much psychological stress, it appears plausible to assume that Pearl's findings exaggerate the difficulties of unplanned conception.

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[11] This estimate is obtained by subtracting from the 3,650 days of the 10 years, 266 days for the gestation period and 42 days for the post-confinement sterility period for each of the 5.36 live children born to the average Hutterite woman who has married between the age of 20-29. In addition, 5 days were subtracted for each of her 71.4 ovulation cycles, estimated to average 28 days.

Low Prevalence Rate of Sterility

There were only 10 childless Hutterite couples among the 340 who had completed their reproductive cycle by 1950. It is most unlikely that any of these 10 families practiced birth control. It can be assumed that in nearly all cases either the husband, the wife, or both, were sterile. This frequency of childless and possible sterile marriages, of 3.4%, is very low. About 10% of the 1977 couples reported in the Indianapolis study were unable to have a child (Whelpton and Kiser, '50 : 339). There also are few small Hutterite families. Only 33 women, or about 10% of the women with completed families, had three children or less.

The Social-Psychology of Fertility

The Hutterite population between 1880 and 1950 has clearly violated what sometimes is assumed to be a "law" of population. Their fertility has steadily increased, while at the same time they have become more and more integrated in America's technological culture. This finding, together with the facts that conception is relatively efficient and childlessness is relatively infrequent in this group, could be interpreted to support a social-psychological theory of fertility. Other theories, such as the presence of a genetically transmitted tendency for high fecundity, cannot be ruled out. However, researchers in the field of psychosomatic medicine have long suspected that social-psychological factors play an important role in determining fertility. The positive cultural emphasis on childbearing, which is accepted by most Hutterites, might be the crucial factor in their high fertility. It is well known that emotional states can support or disturb the glandular balance of the human body. Psychic stress could lead to sterility in some persons. Such stresses are found in Hutterites, but they rarely involve problems of parenthood (Eaton and Weil, '54).

MORTALITY

Crude Death Rate

Death is the counter-balance of birth in population growth. In most primitive cultures there is a high birth rate, but also a high death rate. "Natural" checks, as Malthus called social calamities like famine, war and poverty which kill human beings, have stunted the growth of all these primitive populations. The Hutterities differ from other high fertility groups in that they are not affected by these "natural" checks. Their death rates are low.

There is little doubt about the validity of this finding, although Hutterite vital statistics on deaths are not as good as those on births. There are not enough deaths in the group in any one year, or even over a period of 10 years, to permit the calculation of a life table. It is doubtful that more than 1,000 deaths have occurred in the sect since their migration to the United States.

The crude death rate, the number of deaths per 1,000 population, is 4.4 per year.[12] This rate is very low, if compared with others like that of Algerian Moslems (14.8) a group also having a high proportion of young people. The cross-cultural comparison is shown in more detail in table 15.

TABLE 15

Crude Death Rates of the Ethnic Hutterites and Selected Populations

POPULATIONS [1]	CRUDE DEATH RATES
Hutterites (1941–1950)	4.4
Algeria (Moslems) (1949)	14.8
Jamaica (1948)	13.2
United States (1948)	9.9
Israel (1948)	6.6

[1] United Nations Demographic Yearbook ('51).

Age Specific Mortality Rates

The Hutterite crude death rate does not provide a good picture of their health. The expectancy of death in the group is more similar to that of the general American population than is apparent from the examination of crude rates, for the latter take no account of the unusual

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[12] In our 1950 census inquiry Hutterites were asked to list every death occurring in their group between 1941 and 1950. Seventy-one colonies furnished fairly complete replies. A total of 245 persons were reported to have died. Inflating this number to the entire population of the sect, 309 deaths are estimated to have occurred in the last decade. In 1950 there were 8,542 ethnic Hutterites. In 1940, their number is estimated to have been about 5,616. At the midpoint of the period, on December 31, 1945, it is estimated to have been 6,969. The annual crude death rate is therefore:

$$\frac{309 \times 1000}{6969 \times 10} = 4.43.$$

age and sex distribution. Age specific rates provide a more valid method of making a cross-cultural comparison of mortality. They can be used to show how many Hutterites would be expected to die within a given

TABLE 16

Actual Hutterite Deaths, 1941–1950 and the Number Expected on the Basis of 1940 United States Death Rates and 1947 South Dakota Death Rates

AGE	UNITED STATES DEATH RATES [1]	NUMBER OF HUTTERITE DEATHS EXPECTED BY U. S. RATES	SOUTH DAKOTA DEATH RATES 1947 [2]	NUMBER OF HUTTERITE DEATHS EXPECTED BY S. D. RATES	NUMBER OF ACTUAL HUTTERITE DEATHS 1941-1950
Under 1	41.4	125	30.90	93	119
1–4	2.0	24	1.58	19	45
5–14	.9	20	.61	13	30
15–24	2.0	26	1.57	20	14
25–34	2.7	24	2.03	18	16
35–44	4.6	25	2.80	15	23
45–54	9.7	33	6.18	21	16
55–64	20.3	32	14.90	24	15
65–74	44.6	33	80.17	76	20
75–84	99.5	18			10
85 & over	222.5	1			1
Total		361		299	309

[1] The U. S. Life Table of 1939-1941 (White population) is used. The Hutterite rates are calculated from the 245 persons who were reported to have died during the decade of 1941-1950 in our 80% sample. When this frequency is adjusted for the total population, we have only 31 deaths per year, including infant deaths. To achieve at least a minimum degree of stability we are calculating mortality rates for 10 year age categories. Deaths of male and female Hutterites have also been combined to increase further the size of each cell. However, the use of 10 year averages has the disadvantage of concealing age differentials in mortality and covers up trends toward lower mortality due to the improvement of health conditions within the decade. Such improvements may have been considerable, particularly during the last decade, when there has been a drastic shift in the acceptance by Hutterites of modern medical technology.

[2] Rates for South Dakota in 1947 were computed from the following sources:

(1) Population: United States Bureau of the Census ('51).

(2) Deaths: National Office of Vital Statistics ('49).

year, if their death rates were similar to those of the United States white population (table 16).

It is apparent by inspection that the Hutterite age specific death rates are somewhat below those of the United States population except in the 1-4 year and 5-14 year age groups. This comparison is, however, not entirely satisfactory. The United States white population is a conglomorate of many social and status groups, which differ widely in their mortality rates.

The population of the State of South Dakota, being largely rural, offers a more meaningful comparison. Until 1918, all Hutterites lived there and were influenced by its standard of living and medical practices. In 1950, 15 of the 93 colonies were located there. Hutterite and South Dakota rates are fairly similar. Hutterite children under 15 years of age have a greater likelihood of dying than their counterpart in the South Dakota population. The situation is reversed for adults, Hutterites having a greater likelihood of survival in all but the 35-44 year old group.

TABLE 17

Age Specific Death Rates by Sex For Ethnic Hutterites 1941–1950 [1]

AGE	MALES			FEMALES		
	POPULATION	DEATHS	RATE	POPULATION	DEATHS	RATE
Under 15	1805	101	55.96	1838	93	50.60
15–29	903	8	8.86	957	11	11.49
30–44	495	15	30.30	456	19	41.67
45–59	238	9	37.82	212	12	56.60
60 and over	93	23	247.31	81	18	222.22
Total	3534	156	—	2544	153	—

[1] Population adjusted to the midpoint of the 1941-1950 interval.

Sex and Mortality

The death rates of Hutterite women are consistently higher than those of men in every age group except children under 15 and older people over 60 (see table 17). This finding confirms the interpretation made previously in our review of the Hutterite age distribution. Although the number of deaths in the Hutterite population, even over a 10 year period, is quite small, the pattern is sufficiently clear to be significant.

This finding contradicts what is almost a generalization among human populations: Male mortality is higher than that of females. Dublin, Lotka and Spiegelman ('49) have pointed out that this "law" applied to almost every human and many animal species. One of the few exceptions was in the population of India in 1931, where the "average length of life was almost the same for both sexes." The general level of mortality of the Hutterites is very much below that of the people of India, but the two populations are similar in that mortality among the females in the child bearing ages is higher than that of males. Among the Hutterites, the fertility is even higher than that reported for Indians; correspondingly Hutterite female death rates are even higher than those of males, and the males of the sect clearly exceed females in life expectancy during the middle years of life. These facts suggest the hypothesis that a high number of pregnancies has a direct effect in maternal morbidity and mortality and an indirect effect on lowering resistance to general morbidity, even when women get moderately good maternal care.

The sex reversal in death rates is found only in the age period of 15-60, which corresponds somewhat to the period during which women have a large number of pregnancies. Hutterites do not seem to have an unusual number of maternal deaths, but the higher female mortality may result from a general lowering of their resistance during the childbearing period and a decade or so afterwards. Females who survive beyond their sixtieth year of life again conform to the generalization true for other populations. They have a lower mortality than males. For persons under 15 years of age, the death rate of males also conforms to the findings made for other groups. Hutterite boys have a higher death rate than girls.

It was not possible in our study to test this hypothesis further by correlating the age of death of women with their number of pregnancies. We were also unable to get reliable records of cause of death on enough persons to see if the theory might be confirmed on the basis of the conditions which precipitate death. Preparations for getting this information are being made in connection with a study of genetics of the Hutterites, now in the planning stage.

Infant Mortality

Infant mortality is an excellent statistical index of public health practices. During the birth process and the first year of life, babies are very sensitive to diseases, injuries and malnutrition. The infant mortality rate is the number of deaths of infants under one year of age per 1,000 births during a specified period of time. The average annual infant mortality rate during the period of 1946 to 1950 was 45 per 1,000.[13]

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[13] There were a total of 1,422 births between 1946 and 1950 in the 80% sample

It is above the rate of 38.3 per 1,000 of the United States in 1945. It is far lower than in such technologically backward areas as Egypt (152.8) or Chile (184.1) (United Nations Demographic Yearbook, '49-'50, '51).

Hutterites place much value on having children. Parents receive considerable economic and social support to give adequate care to their youngsters. They have a great deal of self-confidence about their ability to look after children. In the past this attitude has sometimes kept them from consulting doctors on time, when their infants showed the first signs of severe illness. Their home-delivery practice, despite the conscientiousness and practical experience of their midwives, who deliver about nine-tenths of all babies born, is a handicap in cases of extreme prematurity or unexpectedly difficult deliveries. But with the Hutterites, as with the rest of the American population, the chief baby killers of yesterday, diarrhea, influenza, diphtheria, and pneumonia, have melted away into a shadowy past.[14] Hutterites are now learning about antibiotic and other "miracle" drugs. They have the money to buy them. Their infant mortality will probably drop further in the future.

Social Factors in Mortality

The results of this comparison of mortality rates make a good deal of sense in the light of the social-anthropological observations made by the field staff. Hutterites love and cherish their children as much as anyone. The existence of perhaps 5 or 6 children under the age of 10 in a single family—and such instances are the rule rather than the exception—seems to have the consequence that somewhat less attention can be given to each child than in the average South Dakota farm family. An examination of our rather incomplete records of "cause of death," as reported by parents and colony leaders, suggests that preventable

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from 71 colonies with complete demographic data. In this same period, there were 64 deaths of infants born during 1946 and 1950. Infants born in 1945 but dying in 1946 have not been removed nor have deaths that might come to infants in 1951, who were born in 1950, been added. The birth rate of the sect was quite stable during the period, making this refinement unnecessary.

[14] For example, in July of 1875, 250 Hutterite immigrants arrived in Lincoln, Nebraska, after a long arduous trip by boat from Europe and by train across the United States. Diarrhea broke out among the children. Thirty six died from the disease within a few weeks. In 1918 and 1919, there were a good many deaths reported to have been caused by diphtheria. Such tragedies were also common in the general population. Since 1920, there has been no serious epidemic in the sect.

deaths are common among young people. There are reports of a fair number of accidents. Tragedies such as "fell in a tub of boiling water," or "was kicked by a horse" are found to have occurred several times.

The profound religious conviction of the sect enables parents to view accident and death in a somewhat philosophical spirit. While a dead child is mourned, parents are comforted by the belief that he will enter heaven as an angel. "Nature" sees to it often that he is replaced shortly by a new arrival.

The relatively low death rate of Hutterite adults may reflect the fact that the sect encourages good health care for its members. Hutterites have the resources necessary to pay for the best medical care available. All costs are paid by the community. On the basis of returns from 49 colonies, whose leaders made an estimate of their medical care costs in 1949 or 1950 the colonies spent about 24 dollars per capita per year to provide medical, dental and hospital care and to pay for drugs. As has been previously mentioned the mortality rates for women might be reduced somewhat through better pre- and post-natal care, but it is an open question whether any amount of medical atention could entirely eliminate the physiological consequences of the frequent pregnancies that probably account for the fact that female mortality rates exceed those of males.

The doctor who participated in our field work found that adults with severe and chronic illness were well cared for.[15] Many had visited nationally known specialists and hospitals to be diagnosed and treated. Although there is still considerable room for an improvement of health standards in the care of youngsters, Hutterite adults generally live under adequate sanitary conditions. Some medical supersititions exist, but they do not interfere with attention to severe physical illness. Deaths that could be prevented medically still take place, as they do in all parts of the United States. But their incidence is being reduced rapidly.

In general, Hutterite health conditions, as indicated by their mortality rates, can be inferred to be slightly above those of the general population of the United States. They are a shade below those of the South Dakota population. But it should be noted that in 1940 this state ranked second

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[15] Robert J. Weil, Assistant Professor, Department of Psychiatry, Dalhousie University Medical School, Halifax, Nova Scotia. His judgment is based on fairly thorough physical check-ups of 298 persons and more cursory contacts with probably another 500 individuals, who came to him with requests for medical information of one kind or another.

(exceeded only by Nebraska) among the 48 states in the life expectancy of its population (Dublin, Lotka and Spiegelman, '49: 68).

NATURAL INCREASE

The Crude Rate

Natural increase is the balance of births over deaths. The crude rate of natural increase is the most common method of measurement, common because it requires only crude vital statistics. It is obtained by subtracting the death rate from the birth rate. In the Hutterite population, this rate during the decade of 1941-1950 was 41.5 per 1,000. That is extremely high. In table 18 some comparable rates from modern and technologically undeveloped countries are shown.

TABLE 18

Crude Annual Rates of Natural Increase of the Ethnic Hutterites and Selected Populations[1]

POPULATION	RATE PER 1,000 POPULATION
Hutterites (1941–1950)	41.5
Israel (1948)	20.2
Algeria (Moslem) (1949)	19.3
Jamaica (1948)	17.7
United States (1948)	14.3

[1] United Nations Demographic Yearbook ('51).

The crude rate of natural increase, like all crude rates, can give a very misleading picture of trends. It does not reflect changes in birth and death rates over a period of time, nor the age distribution of a population. Although the Hutterite vital rates have been generally more stable than those of other modern populations, it would be advisable to use a more refined measure of population growth.

Gross and Net Reproduction Rates

Natural increase can be shown more accurately by gross and net-reproduction rates. The gross reproduction rate is the number of girl babies born to a group of 100 or 1,000 women 15-49, on the basis of present birth rates, provided that all of them live through the entire reproductive span. This measure of reproduction is used to show potential fertility per generation apart from mortality. The net reproduction rate is the same as the gross reproduction rate, except that the factor of mortality is also included in its calculation. It is a close approximation of the true rate of replacement of a population if the sexes are nearly balanced, if most of the population is married, if migration is negligible and if birth and death rates remain relatively constant for a considerable period of time. All of these factors, with the possible exception of the last are nearly true of the Hutterites. If 100 women age 15 to 49 have 100 daughters on the basis of present birth and death rates, the population is replacing itself. Its net reproduction rate is unity.

The gross reproduction rate of the Hutterites in 1946-1950 as shown in table 19 is 400.36 per 100 women. The net reproduction rate is 366.44. The difference between the two measures, about 9%, is relatively small. It reflects the low mortality rates of the population. These measures may be compared with demographic data from Palestine, a country where the gross and net reproduction rates have been tabulated for both the technologically advanced Jewish and the more primitive Moslem segments.

The Moslems of Palestine in 1940 had the highest gross reproduction rate (381) recorded in the 1950 United Nations Demographic Yearbook, somewhat less than the Hutterite rate. The net reproduction rates, which take account of mortality rates, differ radically. The mortality of Moslems in Palestine is quite high since the net reproduction rate drops by 43% to 217. Forty-three percent of the Moslem generation is lost through early death, against about 9% of the Hutterites.

The Jews of Israel (formerly the Mandate of Palestine) in 1945 had the highest net reproduction rate (161) of any *modern* population resembling the United States in cultural level and technological development. Jews who failed to reproduce themselves in most west European countries in recent decades reversed this reproductive pattern after migrating to the Holy Land. The Hutterites have gross and net reproduction rates which are about 56% higher than those of the Jews of Israel, but the mortality rates of the two populations are almost identical.

Hutterites can therefore be viewed as a modern population in their death rates but "primitive" in their birth rates. They show how a human population might grow if people believe in procreation without interference with biological reproductive potential, but live under technological conditions that give such a growing population good economic and medical support. The high fertility and low mortality of this sect combine to produce a rate of increase that may be unique in human experience.

The Growth Pattern

Was there any regularity in the Hutterite pattern of growth during the 70 year period under study? Although no complete census enumerations were made during the 70 year span equal in thoroughness and completeness to those of 1880 and 1950, the question can be answered.

There were 9 population estimates made at various times between 1900 and 1947.[16] Most of them were made by Hutterites to satisfy their own curiosity and that of other persons who wanted to report on their way of life. One estimate, that of 1917, was contained in an official petition to President Wilson for exemption from military service because of the pacifist convictions of the sect. It is probably quite reliable. The estimates are plotted as a solid line in figure 4.

TABLE 19

Gross and Net Reproduction Rates of Ethnic Hutterites in 1946–1950

AGE	TOTAL HUTTERITE WOMEN	TOTAL BIRTHS	FEMALE BIRTHS [1]	FEMALE BIRTH RATE	FEMALES IN LIFE TABLE POPULATION U. S. 1940	NUMBER OF FEMALE BIRTHS PER 1000 WOMEN
15–19	301	18	9	5.98	471,388	28.19
20–24	252	291	144	114.29	468,101	534.99
25–29	220	421	209	190.00	463,936	881.48
30–34	180	352	175	194.44	458,922	892.33
35–39	130	224	111	170.77	452,688	773.06
40–44	96	100	50	104.17	444,558	463.10
45–49	76	16	8	21.06	433,333	91.26
Total	1,255	1,422	706	4,003.60 [2] (Gross Reproduction Rate)	3,192,926	3,664.40 (Net Reproduction Rate)

[1] Estimated from total sex ratio at births over the 5 year period (100.8).
[2] Obtained by multiplying the sum of the age specific rates by 5.

The picture of their population growth is similar to the estimates obtained when the life-table survivorship method is used. This method is particularly appropriate in the Hutterite population because its size

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[16] 1900: Zieglschmid ('47).
1915: Zieglschmid ('47).
1917: Zieglschmid ('47).
1922: Clark ('22).
1926: Zieglschmid ('47).
1930: Deets ('39).
1931: Deets ('39).
1944: Zieglschmid ('47).
1947: Zieglschmid ('47).

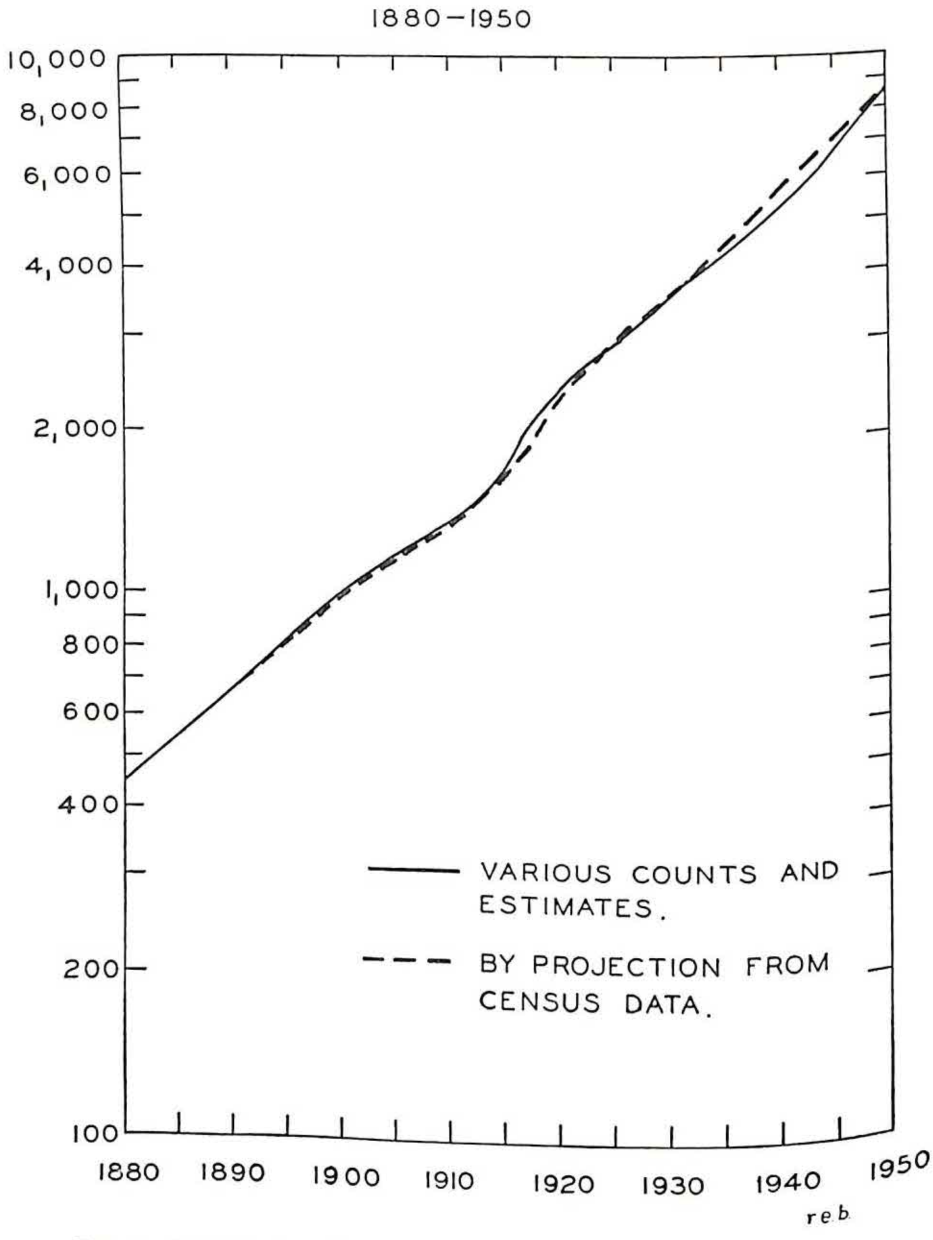

FIG. 4. GROWTH OF THE ETHNIC HUTTERITE POPULATION: 1880-1950.

and composition since 1920 was little influenced by either in- or out-migration. Life tables for the white population of the United States have been used as the most appropriate ones available to estimate Hutterite mortality rates. Using this method the 1950 population was projected backward to 1910. It was inadvisable to project backward any farther by this method since the cumulative errors become too great. Instead the 1880 population was projected to 1910 by using an average of the birth rates over the last 20 years as a measure of births in that earlier day and United States mortality rates appropriate to 1880 to compute deaths. The estimates so obtained are plotted as a broken line in figure 4.

Migration and Population Growth

The two projections fit together almost like the halves of a torn piece of paper. This is not surprising in view of the fact that migration, the social factor which is so important in the growth pattern of most modern populations, is relatively unimportant among the Hutterites. During the first few decades of the sect's residence in South Dakota, there was some movement of people into the colonies. The family groups are known to have joined up between 1880 and 1895. Another family which left Bon Homme Colony in 1878 returned a decade later. These families eventually contributed a total of 98 children who remained in the colonies. All but two or three married after they grew up. Also at least one single girl and possibly half a dozen others joined the colony to marry. They came from a group called " Prairieleut " or " Hutterite Mennonites." They were members of the same ethnic group in Russia that migrated with the colony people to the United States, but had decided to try life on an individualistic basis.

As the years went by, the cultural gap widened between the Colonyleut and the Prairieleut. The latter were more responsive to the assimilative pressures of the American environment. Their movement into the colonies stopped before the turn of the century. This study is therefore based exclusively on the descendants of the original colony Hutterites and those who joined them prior to 1895.

The accession to the population base of contemporary Hutterites was not balanced by any desertion of individuals or of families to live " life on their own." We know of only 7 small family groups and three single individuals who left prior to 1918.

The net effect of the known in- and out-migration prior to 1918 can be shown most clearly if the membership of the colonies of 1880 is corrected for individuals who were then alive and who joined or left the group before 1918. Instead of the 443 persons enumerated by the census, there would have been 472, an increase of 6.5%.

The balance of migration since 1918 has been slightly in favor of reducing the number of Hutterites. There was no new influx of *ethnic* Hutterites.[17] We found that 106 Hutterite males and 8 females were listed as being "deserters" in the 1950 census. We do not know in all cases if these "deserters" were still living at that time. If all were alive, they would constitute one of every 20 Hutterite males age 15 and over and one of every 250 females living on December 31, 1950.[18] The net effect of in- and out-migration since 1918 has probably reduced the size of the contemporary population by about one or two percent from what it would have been in 1950 if all persons ever born into a colony since 1918 could have been enumerated.

A Stable Population

The Hutterite population growth during the last 70 years resembles the statistical model of a *stable* population. Such a population must be distinguished from a *stationary* population. The latter is neither growing nor decreasing. It remains, as the term indicates, stationary in size. A stable population may be growing or decreasing, but it has a constant net reproduction rate. The true birth and death rates are stable. The total number of persons can change, but the percentage distribution by age and sex does not. The statistical model of a stable population has never, to our knowledge, been found in nature. The Hutterites come very close to showing its characteristics. We recall from figure 2 that the population pyramids of the sect showed an approximately similar shape from decade to decade, particularly after the year 1910, although the number of persons increased rapidly.

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[17] Eleven adult converts of non-Hutterite stock with 19 children were brought into several of the colonies after 1930. Some of the children have recently married ethnic Hutterites and have had 34 offspring by December 31, 1950. This group of 64 converts or children of convert marriages constitute less than one percent (.74%) of the entire ethnic population. They have been excluded from our study in view of their variant cultural background. Also excluded have been the populations of certain pacifist communal groups, who have adopted the name "Hutterite" in recent years. They do not intermarry with the ethnic group and have no formal relationship with them, although they have received some financial aid and spiritual advice from the ethnic Hutterites. These settlements, with a population of approximately 900 are located in England, Ontario, Canada and in Paraguay and Uruguay. All have been organized since 1930. Their membership is composed of diverse nationalities, formerly "worldly" persons. They became converted to a creed similar to that of the Hutterites in its emphasis on communal property, pacifism and adult baptism. However, they adhere to more modern customs and values in many areas of every-day living.

[18] There were 5 colonies in 1950 with 131 members, who were excommunicated for their failure, or that of their leaders, to live up to all orthodox prescriptions of the council of preachers. They are the most assimilated wing of the sect. They were included in our study of the culture because they are all of Hutterite ethnic origin, share property on a communal basis and adhere to many of the precepts of the Hutterite religion.

This finding is more than a statistical curiosity. It indicates that it is meaningful to compare the rates of phenomena within the sect at different times, because the composition of the population base remains the same. Within the Hutterite population even crude rates can be a basis for comparison over time.

Future Growth Predictions

At present rates of reproduction the Hutterite population would increase rapidly as shown in table 20. It cannot be over-emphasized that this is not a prediction of what will actually happen. The statistics are based on the assumption that there will be no change in the biological and social factors which have enabled the Hutterites to reproduce rapidly in the past. As shall be shown later, there are slight indications that the social factors governing fertility may change within the next few decades, resulting in a slowing down of the Hutterite rate of growth.

The true rate of natural increase was calculated by the method suggested by Glass ('40). It shows an increase of 4.1265% per year, or a doubling of the population in about 16 years. It was also found that the past growth pattern of the sect could be fitted to an exponential curve. Three exponential curves were used. Curve A is based on growth data up to 1920, a period in which the rate of growth was slower, due to higher mortality rates among the Hutterites in their first decade in the United States. It obviously underestimates, even by 1950, the actual rate of growth. Curve B is an exponential based on the 1910-1950 rate of growth. Projection as far as the year 2000 shows that it represents a faster rate of growth than the true rate of natural increase in 1946-1950. This suggests that between 1910 and 1940, Hutterites were increasing more rapidly than between 1940 and 1950. As mortality was somewhat higher we can only conclude that fertility was much higher also. This is another piece of internal evidence pointing to a possible reduction in fertility among the Hutterites in the past few years.

Exponential Curve C was fitted to the rate of growth over the entire

1880-1950 span. It closely resembles the projection of the true rate of natural increase. Thus the present true rate of natural increase approximates the long term rate of growth of the Hutterites.

It is difficult to believe that the Hutterites will actually attain any such numbers shown here. It is certain that as their numbers become larger they will attract more and more interest, both from their immediate neighbors and from the world at large. They will no longer be able to live in their present tranquility and relative isolation. Their increase in numbers also may undermine the primary group structure supporting their cohesiveness. It is already becoming impossible for the Hutterites to maintain the informal relationships which characterized intercolony contacts during the first few decades of the twentieth century. Only recently the group has found it necessary to draw up a paper of incorporation as a church body. New ministers, who in the past could be confirmed by the council of preachers with every member knowing them intimately, will be known less and less intimately in days to come.

TABLE 20

Projections of Population Growth of the Ethnic Hutterites Under Given Assumptions

YEAR	POPULATION BASED ON TRUE RATE OF NATURAL INCREASE [1]	EXPONENTIAL CURVE A [2]	EXPONENTIAL CURVE B [3]	EXPONENTIAL CURVE C [4]
1950	8,542 [5]	5,115	8,335	7,695
1955	10,400	—	—	—
1960	12,700	8,800	13,090	11,530
1965	15,700	—	—	—
1970	19,200	—	—	—
2000	64,500	37,350	79,530	58,250

[1] The true rate of natural increase based on the 1946-1950 net reproduction rate was 4.1265%.

[2] Based on Exponential Curve log Yc = log 1.002610X +) log .078481 representing the actual population growth 1880-1920 and projected forward from 1920.

[3] Based on Exponential Curve log Yc = log 1.626969X + log .097968 representing the actual population growth 1910-1950 and projected forward from 1950.

[4] Based on Exponential Curve log Yc = log 1.271324X + log .087836 representing the actual population growth 1880-1950 and projected forward from 1950.

[5] Census count.

It will become increasingly difficult to maintain the uniformity of belief and practice which has been an important factor in Hutterite survival.

Their great growth potential constitutes one of the most serious direct threats to their continued existence as an autonomous culture. Not the Malthusian "iron law" of subsistence but a perhaps more inflexible law of antithesis between primary group relations and group size will help to bring about a gradual assimilation. The more Hutterites exist, the more colonies they form, the larger the number of contacts which in-group members make with the larger American culture. The rate of acculturation and assimilation is likely to increase even more rapidly than the population. Already there are signs that there are doubts about some of the fundamental beliefs of their system of religious values, which is an essential factor in their high true rate of reproduction. Long before their colonies begin to show overt signs of disorganization, birth rates may be a reliable indicator of the rate of change of fundamental Hutterite beliefs under the impact of competing American values.

A SOCIAL-PSYCHOLOGICAL THEORY OF POPULATION GROWTH

The Hutterite Data and the Pearl-Reed Logistic Curve

For more than a century and a half, men of science and metaphysics have shown an interest in discovering a law of population growth. Of necessity, their theories had to be "educated" guesses. They usually had to be based on qualitative impressions or official demographic statistics. Both types of data are inadequate to observe a human population over a long period of time under conditions approximating those of a controlled scientific experiment. The Hutterites have provided a unique opportunity to test some of these theories and to observe the dynamics of population growth under fairly controlled conditions.

Ideal conditions of control have been achieved only in the study of animals. Raymond Pearl experimented with populations of *Drosophila melanogaster* in half-pint milk bottles. On the basis of his findings and some other biological growth data he came to the conclusion that the biological pattern of human population growth could be described best by a logistic curve. This curve has three characteristics:

1. a slow rate of growth at the beginning
2. a fast rate of growth in the middle
3. a slow rate of growth at the end, which levels off and finally becomes asymptotic.

This mathematical model was an excellent description of his data, but its application to human beings does not necessarily follow, even though both human and animal species share certain biological qualities. There are some very crucial social-psychological differences. Unlike all lower animals, men can say *no* to reproduction. There are no celibate *Drosophila*. Human reproduction is an activity carried on within strict social rules, which in most cultures are among the most rigid and cherished proscriptions or taboos.[19]

We were unable to fit a logistic curve to the growth pattern of the Hutterite population from 1880-1950, as there was no point of inflection on the upper end of the curve. Ultimately, it may well follow such a pattern, but our data contain no biological clue that would permit us to predict how long the fertility of this population will continue to remain high, when it will begin to decline, how fast it will decline and whether the decline will be continuous. We showed previously that the rate of growth was somewhat slower prior to 1910 than after that date. Higher mortality and disease rates during the early years probably can explain this phenomenon rather than any change in fertility. There also is the suggestion of a slight diminution in the rate of growth in the latter half of the 1940-1950 period, accounted for by a drop in the age-specific birth rate of women age 35-39. In a few more years we shall be able to check whether this is merely a fluctuation around the general trend, or whether it is the beginning of an actual decline in the rate of growth. If and when the decline comes, we suspect that it will come despite a further improvement in health conditions of both mothers and children. It will be caused by a shift in Hutterite attitudes towards birth-control. As we show later, some evidence is now available that such a shift in outlook in favor of controlled parenthood is in the making.

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[19] The big biological and social differences that separate man from lower animal forms are considered to be irrelevant by Raymond Pearl for natural human population growth:

"Probably a real understanding of the problems to which Malthus addressed himself is going to come more from the intensive study of lower forms of life in the laboratory, under physically and chemically controlled conditions, than from any manipulations of never quite satisfactory demographic statistics." Pearl, '25: 4-5.)

"The half-pint universe of the laboratory *Drosophila*, in its quiet incubator, is without doubt a simpler world than that in which we carry on, but in both the great realities of birth and death are the same. And it is these that count." (Pearl, '25: 18-19.)

The Hutterite Data and Malthus

Rev. Thomas Robert Malthus, often regarded as the founder of demography, postulated that human populations have a biological tendency to increase in a geometrical ratio with each generation (Malthus, '33). On the basis of what was happening in the United States he thought that under favorable conditions population would double in number approximately every 25 years. Malthus believed that the human race could not long continue increasing at this theoretically possible level. Food and other resources could not be increased at the same rate. He regarded vice, poverty, war and disease as natural checks to prevent such a calamity. He urged abstention from sexual relations and delayed marriage as being socially and morally more acceptable alternatives to prevent the calamity of mankind increasing in numbers until there would be "standing room only" on the globe (Ross, '27). Rev. Malthus might have come to an even more pessimistic conclusion if he could have seen the Hutterite demographic data. Their rate of growth has been far faster than the rate which Malthus postulated at the dawn of the nineteenth century.

Neither vice, poverty, disease nor war has been a factor in recent Hutterite history, during which their phenomenal growth has taken place. The sect's means of subsistence has increased more rapidly than their numbers. When their ancestors arrived in 1830, there was barely enough money to keep body and soul together. Contemporary Hutterite colonies are highly mechanized. The people live in well built homes. They enjoy excellent credit. Because of the belief that austerity is a religious virtue, their furnishings, clothes, and food are simple but they are adequate. No Hutterite in a colony has ever applied for or received public welfare assistance, even during the depression years. The average colony has about 6,000 acres of land, with a good water supply, electricity and a telephone. It has been able to save enough money to purchase new land and equipment and to build homes to establish a branch colony every 10 to 15 years. Hutterites, despite their rapid growth, are more prosperous today than they have ever been during the 70 year period under review.

Birth Control Practices

Birth control is a major factor affecting the demographic pattern of all modern populations. Hutterites often refer to it as murder. One informant warned that "worldly" people who engage in the practice will have to face on the Judgment Day the hundreds of unborn children whom they have "killed." But religious belief alone is no proof of practice. Catholics have equally strong theological objections to birth control, but their fertility in urban areas is becoming more and more similar to that of persons of equivalent education, income, and social status, who have no stated religious objections to planned parenthood.[20]

The evidence is good that among Hutterites religious conviction and nuptial behavior correspond closely. The net effect of birth control practices on fertility during the period 1880-1950 has probably been close to zero, except perhaps since 1945.

We have learned of about half a dozen cases where Hutterite women were given clear-cut medical advice against further pregnancies because of serious hazards to their health. In one instance, the couple decided to use effective pharmaceutical measures of birth control. In all other cases, they seemed to have been unwilling to assume the responsibility for such a "grave sin," even upon the advice of a doctor. Some asked the doctor to perform a sterilization operation. There seems to be no theological objection to this procedure because the doctor assumes responsibility for the act.

This form of birth control is rather unusual. As has been indicated previously, the Hutterites are a medically sophisticated people. They often consult doctors. In the course of medical examinations by the physician of the field staff the presence of a number of abdominal scars among women over 35 years old was noted. It was his impression that the incidence of hysterectomies and other sterilizing operations was rather high. Whether this impression is correct awaits verification. However, our data does seem to suggest that there may be some effort to control natural fertility at this age level. The extent to which the recourse to a hysterectomy represents a conscious attempt to limit births is, of course, impossible to measure. It is plausible that a certain amount of rationalization takes place in the mind of a 34 year old mother of 8 children when faced with an operation that, in many cases, is elective and sometimes may have been medically unnecessary.

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[20] According to the findings of the "Indianapolis" study, almost 90% of all 1,080 couples included in the area sample tried to control the number of children and their spacing by means of contraception. "Nearly all of those who did not make this effort were "relatively sterile," for over 98% of the "relatively fecund" couples practiced contraception. There is no doubt that birth control practices are widely used in both Catholic and Protestant groups, although Catholics in general were 18% more fertile than Protestant unions. (Vols. I and III.) About two thirds of the couples began their attempts to plan fertility at marriage; about half of the remainder began before the end of the first puerperium." (Whelpton and Kiser, '50: 253.)

The Hutterite taboo is strongest against the use of mechanical or pharmaceutical birth control devices. The rareness of their use was unanimously agreed to by all medical informants and pharmacists with whom the problem was discussed. These impressions are strongly corraborated by the opinion expressed by all Hutterites. *Coitus interruptus* is also regarded as sinful. The "rhythm" method, which is not very reliable but is sanctioned by the Catholic Church, is neither permitted nor prohibited. The Hutterites have no official theological position, although several members were "not sure that it is right." It is doubtful that prior to about 1940 more than a very few knew of this method. At the present time, the rhythm method may be used intermittently by a few couples in some colonies. Hutterites also have no theological mandate to have sexual relations. Couples who wish to keep their family size low may abstain without fear of committing a clearly defined "sin." There is no way of estimating the effect of abstinence on the Hutterite birth rate, but we doubt that it is very great.

There is no economic pressure for planned parenthood. The communal colony of the sect provides equally for all families, regardless of size. The birth of another child in no way lowers the standard of living. The carpenter just makes another bed. The family may be given an apartment with an extra room and if the mother needs additional household help, a relative or neighbor comes in to share the work. The colony pays all medical bills.

The intimacy of personal contact in the primary group structure of each colony also mitigates against the practice of birth control. If a couple has been married for a year without a pregnancy people begin to wonder if the husband or wife is healthy. Mechanical or pharmaceutical devices could not be easily hidden from discovery of friends or close relatives, who come and go freely into any couple's rooms during the day. Those desiring to practice planned parenthood would have to make a deliberate effort to safeguard themselves from discovery, which would in itself be noted quickly. People would begin to gossip about: "What do they have to hide?"

To sum up, birth control practices are generally frowned upon. At least until about 1945, they did not influence the birth rate. Some of our demographic data indicate that since that time the Hutterite acculturation to American values may be having an effect on the fertility of women in their late thirties.

Population Growth is Influenced by Social-Psychological Factors Within Biological Limits

Women cannot conceive before the age of menarche. They must have access to fertile human male sperm. They need about 9 months to have a baby. They become infertile after their menopause. But within these biological conditions, human values, customs, and socially influenced health standards determine the growth of population.

There is no doubt that individual human beings vary in fertility. Some of these variations could have a genetic basis. If they do, the Hutterite population should show it. The existence of a genetic factor cannot be ruled out, but the weight of evidence of this study indicates that high fertility is largely determined by religious values and good medical care within a social system which provides high prestige and adequate economic support for those with large families. Since social mobility is regarded negatively and salvation after death is the most cherished goal, unlimited parenthood helps rather than hinders the life chances of a Hutterite couple.

CONCLUSIONS

An Experiment of History

The Hutterite population has grown rapidly in a fairly stable pattern for 80 years and more, under controlled conditions almost comparable to those obtained by Raymond Pearl with *Drosophila melanogaster* in their "milk bottle universes." The entire population of 8,542 persons including their leaders were not merely passive objects of scientific scrutiny. The Hutterites collaborated actively in this undertaking. They generously furnished most of the data, made extensive searches of their colony records and responded to hundreds of written or verbal inquiries. Social scientists cannot experiment with human fertility, but historical accident has provided them here with a population which meets most of the conditions of a good ex-post-facto experiment.

What set of circumstances made this experiment possible? Among the most crucial factors may be the migration of the Hutterites to North America where good medical care became available to them. In this fortune they are not unique. In 1953 there were 172 million other Americans and Canadians on the North American half of the continent who had access to the same facilities. The Hutterites maintain a high level of fertility, virtually uninfluenced by any form of birth-control. In this also they are not unique. Many primitive populations live so.

Finally, the Hutterites have a strong primary group cohesiveness and a well integrated religiously sanctioned value system, with much emphasis on mutual aid. The group guarantees each individual an equal and adequate, but austere standard of living, regardless of personal ability or fortune. The Hutterites are not unique even in this characteristic. They share these beliefs in Christian community living with many a religious order, particularly those of the Catholic Church. What is unique is the combination of the three factors. This combination makes the Hutterites appear to be "tailor-made" for a fairly well controlled study of many human problems, including the social biology of very high fertility.

Be Fruitful and Multiply

The Hutterites follow to the letter this biblical admonition to Noah. Women living in 1950 had on the average a probability of having 12 children if they were married during their eighteenth year and lived with their spouse through the end of their fertility period. The population was increasing at a rate of 4.1265% per year, or doubling in number in about 16 years. At this rate of growth it can be predicted that there will be 12,700 Hutterites in 1960, living in perhaps 130 colonies instead of the 93 in existence in 1950.

The rapid growth is taking place within a relatively stable pattern. This attribute facilitates a comparison of vital statistics of the group over time, since they are always based on a population which, despite its increase in numbers, remains stable in age and sex distribution. This fact greatly enhances its value as a social laboratory. Future studies, in which the members might be willing to cooperate, can be made with larger and larger numbers of subjects.

The rapid increase in population perpetually confronts the sect with the problem of maintaining its primary group structure, which may be essential for its survival as an autonomous culture. This is accomplished through the process of "swarming" as the Hutterites picturesquely refer to their custom of establishing a branch colony whenever the population gets much above 100.

Accent on Youth

There are two ways in which a population may remain predominantly youthful. In the "primitive way" individuals die prematurely; in the "Hutterite way" there is constant expansion through a very high birth rate. Although in the latter case adults live a long time, they are perpetually outnumbered by successive and increasing waves of children, most of whom survive. Over 61% of the Hutterite population in 1950 had not reached full adulthood. Such a population could not be supported easily in a highly individualistic and competitive economy, where each individual and family strives to maximize its standard of living. Through group responsibility for each member, Hutterites assure security from birth to death.

Young people are not without opportunities for satisfying their aspirations, although the Hutterite culture imposes many limitations. Many of the goals common to most young Americans are taboo to the Hutterites, including such central values as "getting ahead in the world" or a maximum utilization of new inventions designed to increase creature comforts. Hutterites recognize that their way of life is what they call "a narrow road," but they teach their young people to travel it in order to attain religious salvation. The Hutterite youth have opportunities for achieving the aspirations sanctioned by their value system. New branch colonies are established frequently. This expansion provides opportunities for persons who want to be farm department heads, managers and preachers.

Over-all Low Mortality

Hutterites are a "primitive" population in having a high fertility pattern, but are quite modern in their mortality rates. Adults tend to live longer than other American whites and Hutterite children under 15 have a slightly higher death rate. There is evidence that the sophistication of Hutterites about medical care is growing. This probably will reduce the number of juvenile deaths. Since over half of the group is composed of children under 15, a reduction in the death rate of children would increase still further the already high net-reproduction rate of the group, unless this trend is counter-balanced by birth control measures.

Men outlive their wives

Unlike the situation in most other populations, Hutterite men tend to outlive their wives. This dramatic reversal of the generalization that females are the "stronger" sex with regard to longevity is probably largely a result of the very high fertility of Hutterite females. Few Hutterite women die because of pregnancy or in childbirth but it is probable that the frequent repetition of child bearing lowers their resistance to morbidity. We do not know if the relationship between fertility and mortality is linear and direct. There may be an optimum number of pregnancies which have no unfavorable effect on longevity, but beyond which such effects begin to set in. The implications need to be studied further.

Fecundity versus Poverty

The claim advanced by the nutritionist de Castro ('52) that the hungry peoples of the earth are the most fertile is certainly not borne out in the case of the Hutterites. Not only are the Hutterites amply fed but their fertility has increased since their early days in this country when their diet was often far less adequate than it is today. The steady rise in fertility coupled with an increasing standard of living completely contradicts the concept of de Castro, in so far as this group is concerned.

Fertility Decreases Slowly With Age

The population fecundity of the Hutterites has been estimated to lie within the range of 12 to 14 live births for the average woman who is exposed to pregnancy throughout her reproductive period from menarche to menopause.

The peak of fertility of the population lies at the 22nd year of life, when 7 of every 10 women who were married between 1941-1950 had a live birth. There was an average of more than three babies per woman if they were married during the 20-24 year age span. Fertility declined gradually, but not rapidly. At 39 one in three Hutterite women had a child annually. In the forty-sixth year, only one in ten women had a baby, and after that age fertility dropped very rapidly. Nevertheless, there were 86 chances per 1,000 that a woman who had lived with her husband between her forty-seventh and her fifty-first year of life became a mother.

The high fertility of the Hutterite population is not due to the presence of a small number of extremely fecund couples. It is a result of a generally high level of reproductivity. No Hutterite female had more than 16 children. Nor does the birth rate reflect an unusually large "litter" size. Twins were only about as common as they are in the general population.

The Reproductive Efficiency of Human Beings

Our evidence disagrees somewhat with that of Raymond Pearl concerning pregnancy in families which do not engage in controlled parenthood practices. Despite the short life span of both the human ovum and the sperm, copulation among the Hutterites results in conception with far greater frequency than would be expected from the reports of families whose fertility patterns were studied in detail by Pearl.

The total sterility rate of Hutterites is low. The number of women who had no children at all at the conclusion of their reproductive period was only 10 out of 240 or about 3%. Both of these facts taken together seem to suggest a higher rate of reproductive efficiency among human beings than has generally been believed in the past.

Implications for Aid to Underdeveloped Countries

The Hutterite culture is not unique in its positive emphasis on fertility. In many parts of the world people believe, for religious or nationalistic reasons, that maximum reproduction is a virtue. Areas like Japan, China, India and Java are densely populated. Most of their inhabitants know nothing about planned parenthood practices. Their religious values are often opposed to such practices. The Malthusian checks of poverty, disease, and malnutrition operate in these areas to keep population growth far below the Hutterite level.

The United States government is now giving technical aid to many of these underdeveloped regions. Agricultural, industrial, and medical "missionaries" are introducing tractors, penicillin and powdered milk. Major famines and epidemics which have reduced population of these technologically backward areas, are being gradually eradicated. The Hutterites demonstrate what might happen as these people begin to live under modern sanitary conditions without practicing birth control. Death rates will decline sharply, but fertility will remain high for a fairly long period and sharp rates of growth will ensue.

Birth as a Social-Psychological Phenomenon

The birth of a baby is a biological event, influenced by genetic factors many of which are still unknown. Within these limits, the probability of birth, survival, and death is very greatly influenced by social and psychological factors. The high rate of Hutterite reproduction is facilitated by at least 5 social-psychological tendencies:

1. The culture puts much positive value on having children; any form of birth control is regarded as sinful.
2. The community and its values assure economic support to parents who have as many children as they can biologically conceive.
3. Hutterites can and are willing to pay for good medical care.
4. Only a very small proportion of the adults fails to get married.

5. There is little migration, travelling, marital separation, or divorce to separate husband from wife during the fertility period. There are few occasions when married women have no opportunity to reproduce.

Hutterite fertility is not equal to the postulated theoretical level of fecundity because some of their values and customs work against reproduction:

1. Hutterites believe that sex relations prior to marriage are very sinful. Many measures are taken to prevent their occurrence, including strict supervision of adolescents, strong indoctrination of all persons against pre-marital relations and punishment through ritual excommunication (the most severe Hutterite punishment) of any persons who do have such illicit relations.
2. Hutterites believe that no one can be married prior to being baptised. Since baptism can be administered only to mature adults, who show a satisfactory understanding of, and appreciation for the Hutterite creed, few boys and girls are baptized before they reach the age of 19 or 20.
3. Hutterites believe it is "good" for a girl not to marry "too early." The reasons given for this attitude are numerous, such as "I do not want to leave my family too soon" or "When you get married, there is so much more work for a girl." Between 1880 and 1905, the median age of marriage for 78 females was about 19.5 years. In 1950, the median age of marriage of all women then living was 22 years.
4. There are isolated instances of surgical interference with reproduction to protect a mother's health. Certain birth control practices may already be coming into use particularly among women over 35 years of age. They have not had much impact on fertility as yet, but may become a factor in future population growth. The tendency for a reduction in the frequency of sexual relations with increasing age, which has been noted in other populations, may also exist among the Hutterites. It may always have had an effect on keeping their fertility below the theoretically possible level.

The essential core of Hutterite beliefs have changed little during the past 70 years, a period during which the sect has adopted many of the technological inventions of its neighbors. Up to now, Hutterites seem to reverse the general tendency of that human reproduction to decline with the increasing diffusion of modern technology. But the pressures of the American environment are beginning to have an effect (Eaton, '52). New values which might effect fertility are competing with the old standards. Hutterite women talk on occasion about the advantages of "worldly" mothers, who can enjoy life by not being burdened by "too many children." The limitation of family size is increasingly urged by some doctors for reasons of health. These pressures are rarely sufficient to overcome the Hutterite belief that any form of birth control will lead the user to eternal damnation. The cohesiveness of the group is still strong. However, as the acceptance of these competing social values increases, Hutterite fertility is likely to decrease. The two factors are closely related. Hutterite fertility may give a positive indication of major changes in the basic values long before these changes lead to any break-up of a community.

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OSSIFICATION IN A CENTRAL AUSTRALIAN TRIBE *

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INTRODUCTION

So far as can be discovered, there is yet no account of times of ossification in the Australian aborigine. The present study, despite its obvious defects, thus gains some interest from that point of view.

These observations are confined to the members of the Ngalia tribe, together with a very few pure or mixed offspring of neighboring tribes. They were all assembled as a single economic unit in and around the Government Settlement at Yuendumu, some 200 miles northwest of Alice Springs. The "aliens" in the group were not detected until genealogies were checked later. They are indicated in Table I and are included in the results because they show no peculiarities.

Frazer ('33) has pointed out that ossification times differ from people to people and place to place, and are subject to the influence of a number of environmental variables. Whether there are, in addition, really significant differences between different ethnic groups still remains to be settled, however.

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* The material upon which this work is based was collected on a University of Adelaide anthropological expedition financed largely by grants from the Wenner-Gren Foundation for Anthropological Research, Incorporated, New York, and the University of Adelaide.

It is not pretended that the picture presented here is characteristic of the aborigines as a whole. Even given a common hereditary ossification pattern there remains ample scope for substantial differences between these people of the relatively arid interior and those of, say, the more luxuriant north. The present series itself may not be homogeneous from the dietary point of view. The group came under government care only recently. Consequently, while the older members passed their early childhood on a purely native diet, the younger have enjoyed, in addition, access to European food supplements, together with some measure of pre- and postnatal care (see Campbell and Barrett, '53).

Disease may affect bony maturation (Harris, '33). This possibility is not considered here, mainly because of ignorance of the local endemic diseases. Yaws (frambesia) must be fairly common, even in youth, judging from the incidence of "boomerang" or "saber" tibia (plate 1, A), but its effects on growth are unknown. There was no evidence in such people of interference with ossification times.

The number examined were relatively small and age estimations were sometimes uncertain. Consequently, the findings are presented with some reserve. It is hoped that they will stimulate the prosecution of more extensive and better equipped investigations on as many other tribal groups as is still possible.

MATERIAL AND METHODS

The x-ray apparatus employed was a Watson Victor M 1 portable. Power was supplied by a petrol-driven field generator and a portable transformer. The films were 8 inch × 10 inch "Kodarex" which require no intensifying screen. Exposures were mostly at 30 kv. and 10 to 12 milliamps for 2 to 5 seconds, at a distance of 30 inches. Apart from a field check, development of the films had to be deferred until return to Adelaide but the results were almost uniformly satisfactory.

Because of limitations of time and material, radiographs were restricted to the wrist-hand and ankle-foot regions. Both sides were radiographed simultaneously. All the subjects also underwent a full anthropological and dental examination.

Age estimations presented some difficulty. Only in the case of the very young were there any reasonable records. Even then there was

TABLE I: AGE INCIDENCE

Age Group	MALES		FEMALES	
	Ngalia	Other	Ngalia	Other
< 1 mth.	—	—	1 (3 weeks)	—
1 - 6 mth.	—	—	1 (4 mth.)	—
6-12 mth.	1 (8mth.)	—	—	—
12-18 mth.	1 (17mth.)	—	1 (16mth.)	—
18-24 mth.	1 (20 mth.)	—	—	—
2 - 3 yr.	1 (29 mth.)	—	—	—
3 yr.	3	—	—	—
3 - 4 yr.	—	—	1	—
4 yr.	—	—	1	—
5 yr.	1	—	2	—
5 - 6 yr.	—	—	1	—
6 yr.	1	—	2	—
6 - 7 yr.	1	1 (Aranda × Ngalia)	1	—
7 yr.	5	—	4	—
7 - 8 yr.	1	—	—	—
8 yr.	2	—	2	—
8 - 9 yr.	—	—	2	—
9 yr.	1	1 (Pintubi × Ngalia)	1	—
10 - 11 yr.	—	—	1	1 (Pintubi)
11 yr.	1	—	—	—
11 - 12 yr.	1	—	—	—
12 yr.	1	1 (Aranda × Ngalia)	—	—
13 yr.	—	—	1	—
* 14 yr.	1	—	1	—
14 - 15 yr.	—	—	1	—
15 yr.	—	—	—	—
16 yr.	1	—	2	1 (Pintubi)
17 yr.	—	—	1	—
18 yr.	—	—	1	—
> 19 yr.	—	—	1	—
Totals	24	3	29	2

* This lad was very precocious physically.

Enclosed group is that used for study of foot phalangeal epiphyses room for an error of several days since, frequently, babies are born while their mothers are on bush excursions, and memory for dates soon fades. All age estimations were checked by such external evidence—mainly physical, and particularly dental—as could be secured. Even with the greatest care, however, there sometimes remained room for error of up to some months.

The excellent kindergarten and school organization on the settlement secured a maximum attendance of the available children from 3 to 11 years of age. On the other hand, there is a regrettable shortage at both ends of the series. The youngest female was 3 weeks of age but the youngest male was 8 months. Obviously, it is misleading to regard these two ages as comparable, but when a center appears before 3 weeks they must be put in anachronistic juxtaposition when trying to establish a *terminus a quo*. There were sufficient adolescent females to provide a reasonable *terminus ad quem* for that sex but most of the adolescent males were out hunting or away in employment, leaving only a very precocious lad of 14 years and another—probably more typical physically—of 16 years.

In dating the results it must be remembered that if a center is already present it must have appeared at an earlier stage: this is indicated by the sign < before the age given. Only occasionally was a center caught at a rudimentary stage that could fairly be assumed as close to its first appearance. If any epiphysis had not fused at the maximum age in the series it was assumed that it would fuse later: this is indicated by the sign > before the age. In the case of epiphyses of metacarpals, metatarsals and phalanges it was possible to determine before complete fusion whether the secondary centers were proximal or distal. After fusion, of course, such distinction is sheer assumption as is, indeed, the postulation of any epiphysis at all. Complete fusion was recorded only when all trace of an epiphyseal line had disappeared. This is later than the standard adopted by Greulich and Pyle ('50) and may set back the apparent time of fusion. However, it seems the only way of being certain that fusion is complete.

The series comprised 27 males, including 3 of mixed parentage, and 31 females of whom 2 were pure Pintubi (a neighboring tribe). Their age incidence is shown in Table I.

SUPERIOR EXTREMITY

TABLE II: Distal Radial and Ulnar Epiphyses

Bone	Appearance		Fusion		Ulnar Styloid	
	M	F	M	F	M	F
Radius	<20 mths.	< 16 mths.	> 16 yrs.	18-19 yrs.	—	—
Ulna	< 5 yrs.	< 5 yrs.	> 16 yrs.	18-19 yrs.	6-7 yrs.	8-9 yrs.

TABLE III: Carpus

Capitate		Hamate		Triquetrum		Lunate Semilunar		Scaphoid Navicular		Trapezium Mult. Maj.		Trapezoid Mult. Min.		Pisiform	
M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
< 8 mths	3 wks.	8 mths.	< 4 mths.	<20 mths.	<16 mths.	< 5 yrs.	< 4 yrs.	< 5 yrs.	< 4 yrs.	< 5 yrs.	< 4 yrs.	< 5 yrs.	< 4 yrs.	<14 yrs.	10-11 yrs.
		"hook" at						tubercle at		ridge at					
		12 yrs.	11 yrs.					11-12 yrs.	11-12 yrs.	12 yrs.	11 yrs.				

TABLE IV: Metacarpal Epiphyses

	I		II		III		IV		V	
	M	F	M	F	M	F	M	F	M	F
App.	<20 mths	<16 mths.	<20 mths	<16 mths.	<2½ yrs.	<16 mths.	<2½ yrs.	<16 mths	<3 yrs.	<16 mths.
Fuse	>16 yrs.	<19 yrs.	<16 yrs.	<19 yrs.	<16 yrs.	<19 yrs.	<16 yrs.	<19 yrs.	<16 yrs.	<19 yrs.

TABLE V: Hand Phalangeal Epiphyses

Phalanx		Dig. 1		Dig. 2		Dig. 3		Dig. 4		Dig. 5	
		M	F	M	F	M	F	M	F	M	F
1	A	<3 yrs.	<16 mths.	<20 mths	<16 mths.	<20 mths.	<16 mths.	<20 mths.	<16 mths.	<20 mths.	<16 mths.
	F	<16 yrs.	<19 yrs.	<16 yrs.	<19 yrs.	<16 yrs.	<19 yrs.	<16 yrs.	<19 yrs.	<16 yrs.	<19 yrs.
2	A	<20 mths.	<16 mths.	* <3 yrs.	<16 mths.	<20 mths.	<16 mths.	<20 mths.	<16 mths.	<3 yrs.	<16 mths.
	F	<14 yrs.	<19 yrs.	<14 yrs.	<19 yrs.	<16 yrs.	<19 yrs.	<16 yrs.	<19 yrs.	<14 yrs.	<19 yrs.
3	A	–	–	<3 yrs.	<16 mths.	<2½ yrs.	<16 mths.	<2½ yrs.	<16 mths.	<3 yrs.	<16 mths.
	F			<14 yrs.	<19 yrs.	<14 yrs.	<19 yrs.	<14 yrs.	<19 yrs.	<14 yrs.	<19 yrs.

* The male child of 20 months showed this epiphysis, but on the left hand only.

A = appearance. F = fusion.

RESULTS

Superior Extremity

Distal radial and ulnar epiphyses (*Table II*)

Radius In the male the distal radial epiphysis had not appeared at 17 months (single case) but was present at 20 months (single case). Fusion was not complete in the lad of 16 years. In the female this epiphysis was bilaterally present at 16 months (single case). Fusion was incomplete at 18 years but complete in the woman over 19 years.

Ulna In the male there was no trace of a distal ulnar epiphysis at 3 years. The series did not include a 4 year old male but the epiphysis was well developed bilaterally at 5 years. In the female, the center was absent at 4 years, present at 5 years. Fusion appears to be about the same time as for the distal radial epiphysis.

These times are not markedly different from those found in Europeans.

Carpus (*Table III*)

The order of ossification of these bones betrays no peculiarities although there is always some inter-variation between trapezium and trapezoid. In the present series one case (No. 2: Pintubi × Ngalia male, aged 9 years) showed apparent retardation on the radial side (right hand only), with the trapezoid ahead of the trapezium (plate 1, C). Another case deserves mention. This (No. 56: a Ngalia male, aged 3 years) showed bilaterally a peculiar center which could be interpreted as either a proximal, additional, epiphysis for the second metacarpal or as a slightly ectopic—and precocious—center for the trapezoid (plate 1, B).

In all instances the female appears to be ahead of the male, both in the appearance of a center and in its maturation as indicated by "facetting," and the development of special characters. Further, while in the male the pisiform center appeared at about the same time as the sesamoids opposite the head of the first metacarpal, in the female the pisiform was 3-4 years ahead of the sesamoids.

No other peculiarities in the way of extra or ectopic centers or bipartite bones were noted. The times of appearance of most of these centers lie within the recorded European range. However, the triquetrum is earlier, as is the appearance of carpal maturation when compared with the figures given by Greulich and Pyle ('50).

Metacarpal Epiphyses (Table IV)

All primary centers were present in the youngest child examined, a female aged 3 weeks. Epiphyses for the first metacarpals were all proximal, those for the remainder all distal—with the possible exception of the second (No. 56) already discussed. There was no trace of any supernumerary digit or other variation and the only sesamoids seen were those opposite the head of the first metacarpal (flexor-abductor and adductor sesamoids).

The time of appearance of these centers in the female is consistently earlier than in the male. Against most European standards (Greulich and Pyle give generally earlier times) all the epiphyses in the female and those of the first and second metacarpals in the male are precocious. Male time of fusion here appears ahead of European, female about the same as European, but the instances are too few for assurance.

Hand Phalangeal Epiphyses (Table V)

All the primary centers were present in the youngest child examined. All the epiphyses observed were proximal; there was none extra or ectopic. In both sexes in both hands the epiphysis of the second phalanx of the thumb was earlier and always larger than that for the first phalanx (plate 1, B, C).

The female adolescent series gave the general order of fusion as distal : proximal : middle. The males were too few to supply much information in this respect. As with the metacarpals, the female seems to be ahead in appearance and behind in fusion, but the series is restricted.

The times of appearance of these epiphyses lie within the European range as given by Greulich and Pyle. The times of fusion may be earlier in the males and later in the females, as compared with Europeans.

Inferior Extremity

All radiographs of the foot-ankle region were taken in the antero-posterior position with the foot plantar-flexed. This secured the maximum "coverage" per film, but in some instances the lower end of the tibia and fibula overlapped the hinder tarsal bones and obscured the picture in that region.

Distal Tibial and Fibular Epiphyses (Table VI)

Tibia In the male the lower epiphysis was already present in the

INFERIOR EXTREMITY.

TABLE VI: Distal Tibial and Fibular Epiphyses.

Bone	Appearance		Fusion	
	M	F	M	F
Tibia	<8 mths.	<4 mths.	<16 yrs.	<16 yrs.
Fibula	<20 mths.	*<3-4 yrs.	<16 yrs.	<16 yrs.

* May have appeared at 16 months, but that plate was obscured in this region.

TABLE VII: Tarsus.

Calcaneum Os Calcis		Talus Astragalus		Cuboid		Cuneiform III		Cuneiform I		Cuneiform II		Navicular Scaphoid	
M	F	M	F	M	F	M	F	M	F	M	F	M	F
< 8 mths.	< 3 wks.	< 8 mths.	< 3 wks.	< 8 mths.	* 3 wks.	< 8 mths.	< 4 mths.	<20 mths.	<3-4 yrs.	<29 mths.	<3-4 yrs.	<29 mths.	*3-4 yrs.
				Per. Long notch 7-8 yrs.	8 yrs.							Tubercle 7 yrs.	>5 yrs.

* Just appearing.

TABLE VIII: Metatarsal Epiphyses.

	I		II		III		IV		V	
	M	F	M	F	M	F	M	F	M	F
App.	< 3 yrs.	<3-4 yrs.	< 3 yrs.	<3-4 yrs.	<3 yrs.	<3-4 yrs.	* 3 yrs.	<3-4 yrs.	< 5 yrs.	<3-4 yrs.
Fuse	<14 yrs.	<19 yrs.	<16 yrs.	<18 yrs.	<14 yrs.	<18 yrs.	<14 yrs.	<18 yrs.	<14 yrs.	<18 yrs.

* Just appearing.

Note: Metatarsal V styloid. Male at 6-8 yrs. Female at 5-7 yrs.

TABLE IX: Foot Phalangeal Epiphyses.

Phalanx		Dig. 1		Dig. 2		Dig. 3		Dig. 4		Dig. 5	
		M	F	M	F	M	F	M	F	M	F
1	A	29 mths.	16 mth.	<20 mth.	<16 mth.	<20 mth.	<16 mth.	<20 mth.	<16 mth.	<3 yrs.	<16 mth.
	F	<16 yrs.	<16 yrs.	>16 yrs.	>19 yrs.	16 yrs	<19 yrs.	16 yrs.	<19 yrs.	>16 yrs.	<19 yrs.
2	A	20 mth.	<16 mth.	<20 mth.	<3-4 yrs.	<20 mth.	<4 yrs.	<3 yrs.	?<3-4 yrs.	? 3 yrs.	?<3-4 yrs
	F	<16 yrs.	14-17 yrs.	14 yrs.	>16-18 yrs.	14 yrs.	<16 yrs.	14 yrs.	<16 yrs.	<14 yrs.	<16 yrs.
3	A	–	–	3 yrs.	<3-4 yrs.	<3 yrs.	<3-4 yrs.	<3 yrs.	<3-4 yrs.	? 3 yrs.	?<3-4 yrs
	F			14 yrs.	14-16 yrs.	14 yrs.	<16 yrs.	14 yrs.	<16 yrs.	<14 yrs.	<16 yrs.

A = Appearance. F = Fusion.

youngest examined—8 months. In the female the center appeared between the third week and the fourth month. In both sexes time of fusion was about the same but was obscured by the overlapping referred to above.

Fibula In the male the lower epiphysis was present before 20 months. In the female it may have been present at 16 months, but the radiograph for the individual of that age was obscured and the next—3 to 4 years—is the earliest that can be cited. Time of fusion appeared to be about the same for both sexes but estimates are subject to the same limitations as for the tibia.

These figures show no clear-cut sexual distinction. In both sexes both bones fall within the maximum European range as given by Meschan ('51).

Tarsus (Table VII)

The fact that the major centers for the calcaneum and talus were already well present in the youngest child examined (3 weeks) supports the contention that these centers—as in Europeans—appear before birth. In the same child the condition of the cuboid was consistent with the view that its center appeared at or just after birth. The navicular falls within European extremes. The order of ossification of the cuneiforms is an accepted variant but the times are early. Maturation, as indicated by characteristic sculpturing and the appearance of distinctive features, is generally earlier in the male but otherwise there is little sexual differentiation.

There was no evidence of a special center for an os trigonum on the talus, an epiphysis on the calcaneum or the tubercle of the navicular, nor were any unusual centers discovered. The female aged about 19 years had bilateral tibialis posterior sesamoids.

Metatarsal Epiphyses (Table VIII)

All primary centers were present in the youngest child examined (3 weeks). The epiphysis on the first metatarsal was always proximal that on the remainder always distal. No ectopic or extra centers were observed and there was no separate center for the tubercle (styloid process) of the fifth metatarsal.

Taken all round, the female may be ahead of the male in times of appearance of these centers but there is little evidence except, perhaps, for the fifth metatarsal. The times are close to those given for Europeans. Fusion appears to be earlier than in Europeans in the male, later in the female, but again the evidence is scanty.

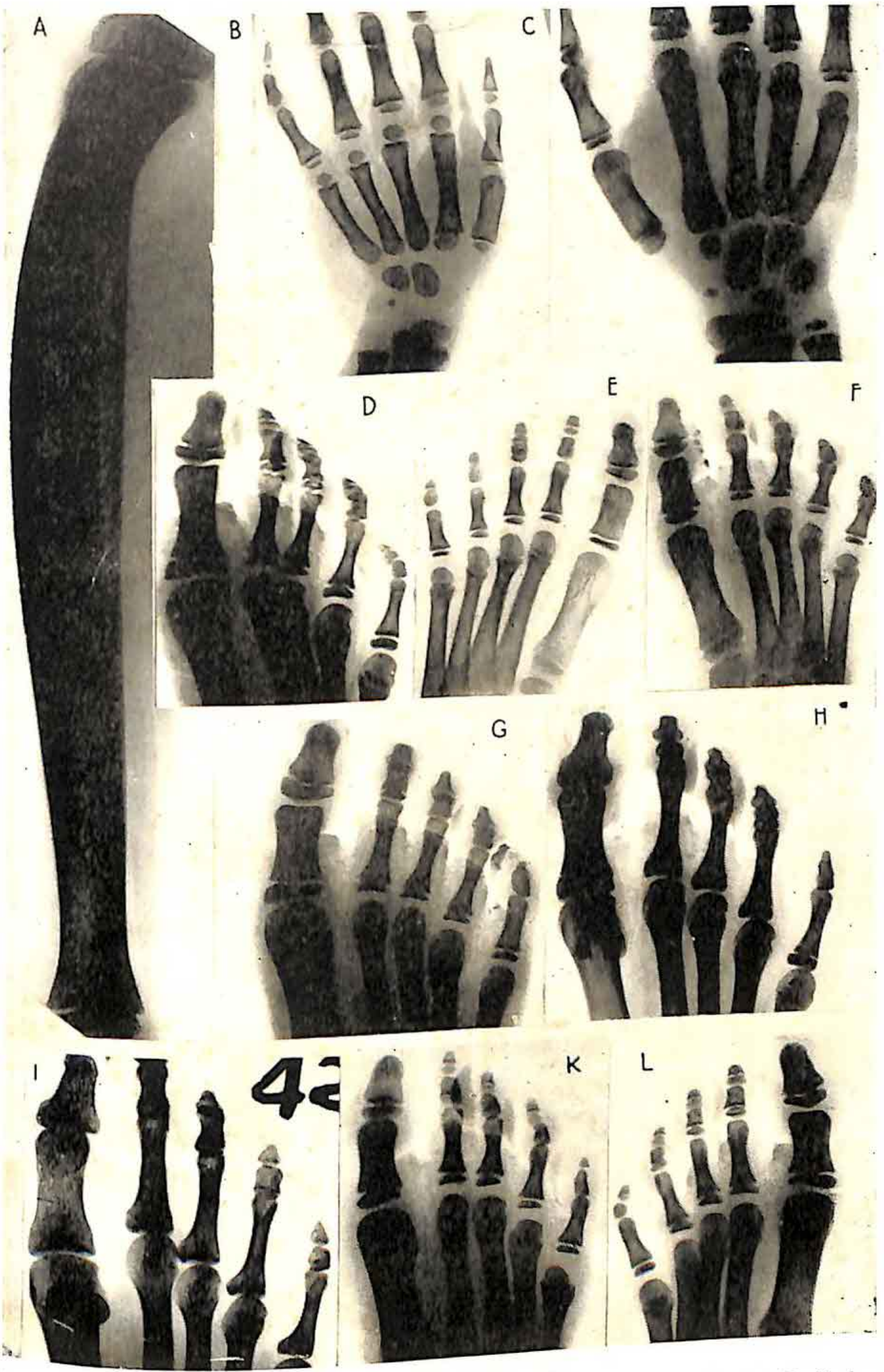
Foot Phalangeal Epiphyses (Table IX)

All primary centers were present in the youngest child. So far as could be determined the epiphyses were proximal except for a possible variant in the little toe, mentioned below. In the big toe in both sexes—as in the thumb, but to a lesser extent—the epiphysis of the second phalanx appeared earlier, and was always larger than the epiphysis of the first phalanx (plate 1, E, F).

Table IX gives times of appearance and fusion for all the epiphyses of all the toes but it should be emphasized that not a single foot attained this ideal. In both sexes in all feet both phalanges of the first toe, and the first phalanges of all the other toes, behaved in "text-book" fashion. However, the middle and distal phalanges of the second, third, fourth and fifth toes were subject to considerable variation. This is shown in Tables X and XI. Here the age group is chosen to ensure inclusion of all epiphyses likely to appear (Table I). The males (aged 5 to 12 years) and females (aged 4 to 13 years) are approximately equal in numbers.

It will be noted that from the second toe laterally there is a progressively greater tendency to suppression of epiphyses in the middle and distal phalanges (Table X). Either phalanx, or both, may be involved but the middle is affected more than twice as often as the distal. It is also apparent that the incidence is much greater in the females in whom more than half had all 4 lateral toes affected and more than three-quarters had at least three toes involved. The male, on the other hand, more frequently showed involvement of only one or two toes.

In neither foot of either sex was there a little toe with its full complement of bony elements. Moreover, the bones present varied considerably in size and shape and often bore little resemblance to either primary or secondary centers (plate 1, D-L). Such bony fragments are best referred to as ossicles. The maximum possible number of such ossicles in the distal two joints would be 4: in fact, in no little toe were more than three observed, two was the commonest number, but one alone occurred occasionally (Table XI). There has evidently been some suppression (or, possibly, very premature fusion) of some centers, but exactly which is not always clear. Thus the middle of three ossicles may, apparently, behave like the epiphysis of the distal phalanx and



A. "Boomerang" tibia. No. 58, Ngalia girl aged 6-7 years.
B. Ectopic trapezoid or proximal epiphysis at base of second metacarpal. No. 56, Ngalia boy aged 3 years.
C. Retardation of radial side of carpus, putting trapezoid ahead of trapezium. No. 2, Ngalia × Pintubi boy, aged 9 years.
D. Three ossicles in little toe. No. 71, Ngalia girl, aged 13 years.
E. Two ossicles in little toe. No. 73, Ngalia boy, aged 7 years.
F. One ossicle in little toe. No. 53, Ngalia girl, aged 4 years.
G. One ossicle in little toe. No. 3, Ngalia boy, aged 9 years.
H. One ossicle in little toe. No. 78, Ngalia girl, aged 16 years.
I. Two ossicles in little toe. No. 42, Ngalia girl, aged 16 years.
(The last three figures are reproduced here to illustrate the point that deficiency of ossicles in childhood is not necessarily corrected during maturation.)
K. The proximal ossicle in the little toe gives the appearance of representing the middle and proximal fused together. No. 98, Ngalia boy, aged 7 years.
L. The distal ossicle in the little toe gives the appearance of representing the middle and distal ossicles fused together. (This is much less common than K.) No. 47, Ngalia boy, aged 7 years.

Note: scrutiny of figures D to L discloses many different grades of epiphyseal suppression in the lateral four toes.

fuse with that or, more commonly, act as the diaphysis of the middle phalanx and treat the proximal ossicle as an epiphysis (plate 1, K, L). That, at least, is what examination of these radiographs suggests but a longitudinal series would be necessary to be sure in any one case.

A point of interest is that these osseous changes in the feet were nearly always symmetrical.

SUPPRESSION OF BONY ELEMENTS IN FEET of 18 Males, aged 5-12 yrs. and 19 Females, aged 4-13 yrs.

TABLE X: Number of Toes Affected.

5th Only		5th & 4th		5th, 4th & 3rd		5th, 4th, 3rd & 2nd		Uncertain		Totals	
M	F	M	F	M	F	M	F	M	F	M	F
4	1	5	1	4	5	3	10	2	2	18	19

TABLE XI: Number of Phalanges Affected.

	Suppression of Epiphyses						*				
	2nd Toe		3rd Toe		4th Toe		Ossicles only	5th Toe		Uncertain	
Phalanx	M	F	M	F	M	F		M	F	M	F
Distal	3	5	2	0	0	0	3	5	5	2	2
Middle	0	5	3	13	9	10	2	12	11		
Both	0	0	2	1	3	6	1	1	1		

* See text concerning 5th toe.

DISCUSSION

Despite some unfortunate gaps in the evidence a few conclusions of interest emerge. In the first place, the times of ossification displayed by the aborigine lie within the total European range as given in standard works by Quain ('15), Frazer ('33), Buchanan ('49), Gray ('49), Greulich and Pyle ('50), Cunningham ('51), Meschan ('51), and others. The most that can be said for the aborigine is that he usually falls into the earlier part of the range. This would be in line with Campbell's ('25) observations on the generally earlier dental maturation in aborigines.

Most writers emphasize that in any ethnic group the female both begins and ends ossification earlier than the male. The figures for the aborigine generally support the contention for an earlier start in females, but what evidence there is suggests a later finish. Here, however, the facts are so scanty that it would be unwise to insist upon the reliability of this interpretation.

One of the most striking results of this—admittedly limited—survey is the almost complete absence of a wide range of possible bony variations as described for the European foot (see, e. g. Wood Jones, '44).

In default of any positive evidence for specific ethnic peculiarities, attention may be directed to what seems to be the most interesting outcome of this study, namely, the evidence for "degeneration" or "recession" on the lateral side of the foot. It is something of an article of faith that such a process is occurring in the European foot, but details are hard to find in standard works on anatomy and even in books devoted entirely to the foot. These all seem to contain an underlying assumption that the full number of bony elements is the rule and that any deficiencies of the moment are the result of delay, to be repaired in time. However, Flecker ('32) has shown that this is not necessarily the case. For urban children of mostly European parentage he reports a condition very similar to that described here for the aborigine, and with the same heavier incidence in the female.

When it receives any attention at all, this suppression of osseous elements in Europeans is usually attributed to the effects of civilized existence and, particularly, footwear. The greater female incidence has been considered confirmatory evidence. But, the fact that the same phenomenon appears at an equal intensity, and with a similar sexual distribution, in aborigines who have never known civilized life or footwear exculpates both factors as possible agents. The process, then, must be part of a common human heritage, associated with increased emphasis upon the medial side of the foot in the interests of stability. The greater intensity in females may reflect special stresses imposed by the broader pelvis and associated bony adjustments.

SUMMARY

1. This paper records the radiological condition of the wrist-hand, ankle-foot regions in 58 Central Australian aborigines of ages from 3 weeks to 19 years.
2. The study as a whole disclosed no ethnic peculiarities.
3. Ossification falls within the time range assigned to Europeans but usually towards the earlier rather than the later limit.
4. An account is given of phalangeal "degeneration" in the foot similar to that found in Europeans.

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FACTORS OF DOSAGE AND HOST DETERMINING ANTIBODY RESPONSE TO SECONDARY ANTIGEN STIMULUS[1]

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A SECONDARY antigen stimulus, according to Glenny and Südmersen ('21) is defined as the injection of antigen into an actively immunized animal. The active immunization may be due to natural infection or to artificial immunization with the same specific antigen. The individual may or may not show evidence of such previous treatment by presence of specific antibody in the serum. The effect of a secondary stimulus is a distinctively higher immune response than that of a primary stimulus. Smaller doses of antigen are necessary to produce a secondary response, than those needed for a primary response.

The primary stimulus, however, is preferred in assays of the relative potency of toxoids, because greater uniformity of response is expected from a non-immune population. In field trials of toxoids in human population samples, one is often faced with a mixture of partly immune and non-immune individuals, so that the interpretation of the response is equivocal. Accurate information of previous immunization is often essential for a reduction of the variability through covariance. The following presentation is an attempt to evaluate the importance of measurable independent variables and their contribution to the variation in secondary response in human beings.

Response is in this work measured by the antibody titer which is one measurement of immune response. Other response measurements such as percentage of survivals or percentage of skin reactions to antigen or toxin, are less informative since they have the limitations of all-or-non-reactions. A fundamental relationship between antitoxin titer and all-or-non-reactions has been well substantiated recently by Holt ('53), and Cavalli-Sforza ('47).

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[1] The experiments were conducted under the sponsorship of the Commission on Immunization, Armed Forces Epidemiological Board, and were supported in part under contract with the Office of the Surgeon General, Department of the Army. Presented at the Third International Conference on Biometrics, Bellagio, Italy, September 2, 1953.

The discussion is limited to the antitoxin titer at a certain time after the antigen injection, which approximates the time of maximum response. The quality of the antitoxin which recently was subjected to intense study by Jerne ('51) is also omitted from this discussion, where antitoxin titer simply denotes the highest dilution of a serum which neutralizes a given dose of toxin to a certain end-point reaction. Since the titers are uniformly determined throughout the assay, this study deals with comparison of response, where the absolute value of the response is unimportant. The notation of the titers in Antitoxin Units per ml (AU) is in conformity with present convention.

Titrations were performed in mice with constant toxin doses and serial 1:2 dilutions of serum.

For a complete analysis of the factors determining a given secondary response the following variables must be included in the experiment and each must be varied over a sufficiently wide range.

1. (y) The dependent variable which is the titer found after the secondary stimulus. Use of logarithm increases the homoschedasticity of the system somewhat, but there is a tendency of larger error at smaller antitoxin levels.
2. The independent variables are:
    a. (z) The size and potency of the secondary stimulus, also transformed into logarithms.

    b. (x_2) Intensity of previous immunization, which includes the dose and potency of earlier antigen exposure and the time elapsed since it was administered.

    c. (v) Pre-immunization titer, i. e., the antitoxin titer of the individual immediately before the secondary dose is given.

    d. (x_1) The inherent ability of the individual to react to an antigen stimulus. This factor can only be assigned qualitatively to groups of subjects with given species characteristics or some somatic abnormality.

The immunization history, the pre-immunization titer and the inherent immunizability together form the immune status. Rarely all the information is available in a human field study. Accurate knowledge of the time and size of previous injection is often missing, so that subdivisions such as "number of injections," "time since last injection," etc., are the only measurable qualities. The pre-immunization titer is sometimes considered a unique measure of the immunization history. Although a high titer suggests effective previous immunization, low titers or titers below the measurable limits may represent all sorts of immune status including the so-called "non-immune" where an antigen injection would provoke a primary response only. The uncertainty as to whether a person has primary immunity is larger in case of diphtheria than of tetanus, since natural immunity is possible in diphtheria while artificial immunization is the only possible way of acquiring tetanus immunity.

Immunizability is measurable as a group phenomenon rather than as an individual characteristic. It can be shown that animal strains of various genetic composition require different doses of antigen to provoke primary response. Thus, we have been able to show that two pure inbred strains of mice differ 12 times in the amount of tetanus toxoid necessary to induce 50% primary immunity to challenge with tetanus toxin. Similar differences were noted in guinea-pigs with respect to diphtheria immunizability (Prigge, '35; Scheibel, '43).

The influence of inherent immunizability on secondary response needs systematic research. The experimental data to be presented afford an opportunity to analyze the four components of primary dose, pre-immunization titer, secondary dose and inherent immunizability in a group of young men. It was possible to conclude that primary dose and primary response were interchangeable measurements and that immunizability is a property which is more pronounced in secondary response than in primary response.

EXPERIMENTAL DATA

The experiment was originally designed to assay the relative potency of four aluminum precipitated toxoids. The subjects were inmates of the Wrentham State School, Massachusetts, of which 128 young men, aged 15-25, were selected because of no previous history of tetanus immunization, which was furthermore confirmed by the fact that none of the subjects showed measurable antitoxin in the blood before the test. Each of the four toxoids were given in either of two doses, 0.1 ml and 0.5 ml, respectively. These eight treatments were repeated 4 weeks after the first injection, but the individuals were distributed according to an 8 × 8 latin square with the primary injections forming one axis, and the

TABLE 1

Primary (v) and Secondary Titer (y) (in log antitoxin + 3) for 128 Individuals, by Primary and Secondary Dose of Tetanus Toxoid

PRIMARY DOSE OF TOXOID

SECONDARY DOSE OF TOXOID	(ml)	z	Toxoid A				Toxoid B				Toxoid C				Toxoid E			
			0.1 ml		0.5 ml		0.1 ml		0.5 ml		0.1 ml		0.5 ml		0.1 ml		0.5 ml	
			0.2		0.9		0.9		1.6		0.5		1.2		0.0		0.7 (x_2)	
			v	y	v	y	v	y	v	y	v	y	v	y	v	y	v	y
A	**0.1**	**0.2**	0.1†	3.3†	0.1	1.7	0.1	2.0	1.0	2.3	0.1*	0.1*	1.6	3.5	0.1	1.7	0.1	1.0
			0.1	3.2			0.4	2.0	1.6	2.6	0.1	2.0	0.4†	3.2†	0.1	2.9	0.1	2.6
	0.5	**0.9**	0.1	2.0	0.1	2.6	0.1*	2.3*	1.3	3.2	0.1	3.2	2.2	1.7	0.1*	1.4*	0.1	1.7
			0.1	2.6	0.1	3.5	0.1	1.1	1.0*	2.6*	0.4	3.2	1.3	3.2	0.1	2.3	0.1*	2.9*
													0.1	2.9			0.4	2.3
B	0.1	0.9	0.1	3.5	2.2	3.6	0.1	1.1	1.6	2.6	0.1	2.9	1.9	2.3	0.1	2.3	0.1	2.6
			0.1	3.2	0.1	2.9	0.1	1.4	0.7	2.6	0.1	2.9	0.1	2.9	0.1	2.0	1.6	2.9
	0.5	1.6	0.1*	3.6*	0.1*	3.9*	1.0	2.9	1.9	3.2	0.1	3.6	0.7	3.2	0.1	2.6	0.4*	3.9*
			0.1	3.2	0.4	2.9	0.1	2.9	1.3	3.5	0.1*	2.9*	1.0	3.6	0.1	2.9	0.1	3.2
							0.1*	3.2*			0.7	3.3						
C	0.1	0.5	0.1	2.9	0.1	2.3	1.6	2.9	1.6	2.6	0.1	3.5	1.6†	2.9†	0.1	1.1	2.2†	2.6†
			0.1	1.7	0.7	2.3			0.4	1.7			0.4	3.2	0.1	2.0	0.1*	3.2*
	0.5	1.2	0.1	3.2	1.0	2.9	0.1	3.2	0.7*	2.6*	1.0	2.6	1.9	2.0	0.1	2.3	0.1	3.2
			0.4	3.9	0.7	2.9	1.3	2.6	0.7	2.6	0.1	3.2	0.1	2.6	0.1*	2.3*	0.1	2.6
					0.1	3.5												
E	0.1	0.0	0.1	0.1	1.3	3.2	1.0	3.2	0.7	2.0	0.1	1.4	0.1	2.6	0.1*	0.1*	0.1	1.4
			0.1*	1.1*	0.1	2.9	1.9	2.9	1.6	2.3	0.1*	0.1*	0.1	2.6	0.1	0.7	0.7*	2.0*
	0.5	0.7	0.1*	0.1*	0.4	2.9	0.1*	1.4*	1.9	3.2	0.1†	3.9†			0.1	0.1	0.1*	2.6*
			0.1	2.0	0.1	3.5	0.7	2.6	0.4*	1.4*	0.1	3.5	0.7	1.0	0.1	2.0		

* Mongoloids. † Dysendocrines.

0.1 indicates values less than lower limit of titration (0.00125 AU).

secondary injection forming the other axis. Thus all 64 combinations of primary and secondary injections were given. (See table 1.)

The columns of table 1 contain the antitoxin titer (in logarithms plus 3). In the left hand part of each column (v) are those titers determined 28 days after the first injection; in the right hand part are the titers 14 days after the secondary injection (y).

RELATIVE POTENCY OF DOSAGE

A previous report on these data, (Ipsen, '53A), dealt with the estimate of the relative potency of these four toxoids, which had also been assayed in both mice and guinea-pigs. The potency estimates were obtained from this assay in humans by construction of reaction curves relating primary response (v) to dose of toxoid.

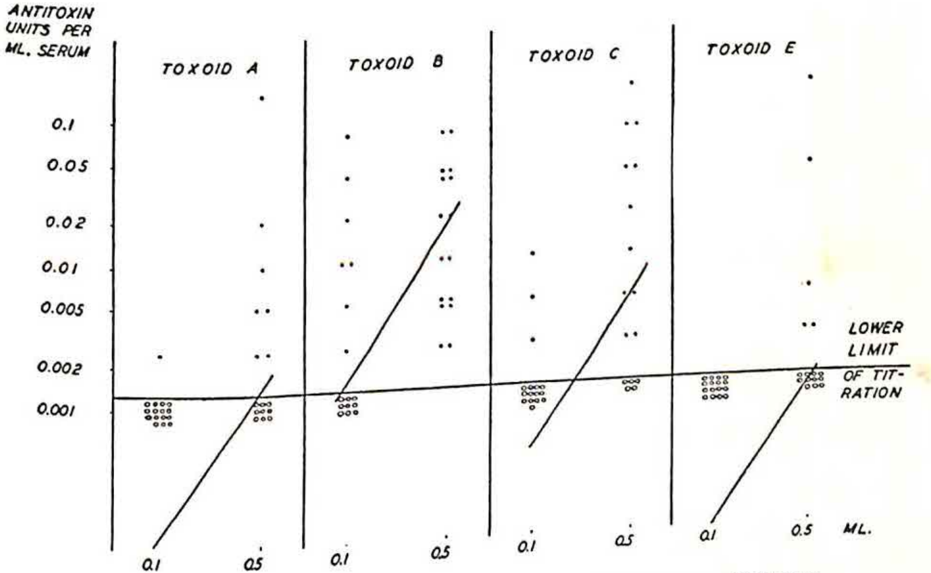

FIG. 1. REACTION CURVES OF FOUR TETANUS TOXOIDS IN HUMANS (PRIMARY RESPONSE)

The reaction curves clearly place Toxoid B as the most potent, Toxoid C of average potency, and A and E as the least potent. The same potency relationship was also found to hold when the secondary responses were related to the secondary dose.

In this particular design each of the groups which received a secondary dose consisted of individuals who had the same average primary immunity status. Hence, no correction for primary immunity is necessary for the estimation of relative potency based on secondary response.

The eight treatments can now be placed in order of relative potency as indicated in table 2. It should be noted that the potency order of the same four toxoids was found to be identical to that determined in mice and in guinea-pigs.

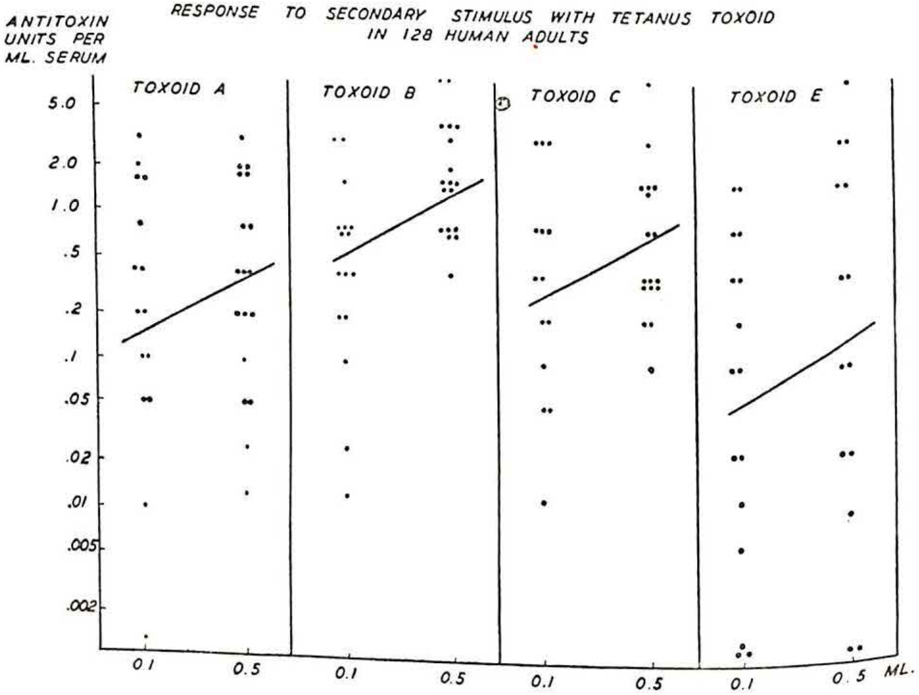

FIG. 2. REACTION CURVES OF FOUR TETANUS TOXOIDS (SECONDARY RESPONSE)

TABLE 2

Mean Primary and Secondary Response, by Potency of Toxoid Dose

Toxoid	Dose	Relative Potency	Log Rel. Potency	Number	Primary Response	Number	Secondary Response	Primary Response*
E	0.1 ml	1.0	0.0	16	0.100	16	1.79	0.51
A	0.1 ml	1.6	0.2	16	0.119	15	2.27	0.40
C	0.1 ml	3.2	0.5	16	0.213	14	2.49	0.66
E	0.5 ml	5.0	0.7	16	0.400	14	2.16	0.36
A	0.5 ml	8.0	0.9	16	0.475	18	2.48	0.43
B	0.1 ml	8.0	0.9	16	0.550	16	2.61	0.57
C	0.5 ml	16.0	1.2	16	0.888	17	2.84	0.51
B	0.5 ml	40.0	1.6	16	1.150	18	3.25	0.47

* Mean titer of group before secondary dose was injected.

REGRESSION ANALYSIS OF PRIMARY AND SECONDARY DOSAGE, DISREGARDING IMMUNIZABILITY

For the biometric analysis, we shall use y (log. secondary antitoxin titer) as the dependent variable, and let the above logarithmic relative potencies substitute for x_2 and z, as measurements of the primary and secondary dosage.

Before assumptions can be made as to primary immunizability, a multiple regression analysis was performed with linear and quadratic terms of x_2 and z and their interactions. Only three terms were found

TABLE 3

Matrix of Sums of Squares and Sums of Products of Deviations from Mean

128 Observations

	z	x_2	zx_2	x_1	zx_1	y
z	31.56					24.91
x_2	0.12	30.40				11.25
zx_2	42.39	23.04	42.39			22.24
x_1	−2.95	1.80	−1.82	24.00		12.31
zx_1	−8.12	0.38	−5.17	17.68	20.39	−2.24
y						100.2437
Means	0.778	0.750	0.580	−0.125	−0.120	2.507

	z	v	zv	x_1	zx_1	y
z	31.56					24.91
v	−0.21	46.11				12.79
zv	15.07	34.21	42.42			15.02
x_1	−2.95	7.39	4.13	24.00		12.31
zx_1	−8.12	5.60	2.20	17.68	20.39	−2.24
Means	0.778	0.487	0.377	−0.125	−0.120	2.507

50 Observations (v larger than 0.1)

	z	v	zv	x_1	zx_1	y
z	12.83					5.03
v	−1.59	16.25				0.96
zv	12.07	10.96	24.13			3.88
x_1	−1.59	3.38	1.01	7.92		1.69
zx_1	−1.65	3.81	0.86	7.45	8.39	0.40
y						18.3442
Means	0.806	1.090	0.847	−0.040	−0.064	2.746

TABLE 4

Analysis of Variance

Primary Dose (x_2), Secondary Dose (z) and Immunizability (x_1)

Component	Sum of Squares	D. F.	Mean Square
Total (y)	100.2437	127	
Regression on z	19.6615	1	
Additional regr. on x_2	4.0898	1	
— interaction x_2z	3.2442	1	
	73.2482	124	0.5902
Additional regr. on x_1	7.5678	1	
— interaction x_1z	4.5401	1	
Remainder	61.1403	122	0.5011
Primary Response (v), z and x_1			
Total (y)	100.2437	127	
Regression on z	19.6615	1	
Additional regr. on v	3.6398	1	
— interaction vz	4.2811	1	
	72.6613	124	0.5860
Additional regr. on x_1	6.5125	1	
— interaction x_1z	4.9122	1	
Remainder	61.2366	122	0.5019
50 Individuals Having v Larger Than 0.1			
Total (y)	18.3442	49	
Regression on z	1.9693	1	1.1320
Additional regr. on v	.1566	1	
— interaction vz	1.3829	1	
Additional regr. on x_1	.5786	1	
— interaction x_1z	1.5727	1	
Remainder	12.6841	44	0.2883

significant (see table 4, Analysis of Variance) so that a preliminary expectancy equation was computed.

$$y = 1.243 + 0.870x_2 + 1.286z - 0.667x_2z \cdots \quad (1)$$

on the basis of the matrix of sums of squares and sums of products of deviations. (see table 3).

The fit of this expectancy for the overall sample of 128 individuals was next tested for smaller groups. Since the inmates of the institution represented a great variety of constitutions, it was pertinent to investigate whether grouping of the individuals in categories of their somatic and mental diagnosis would reveal any group which deviated in response from the overall expectancy to suggest abnormal immunizability of the group.

TABLE 5

Observed and Expected Means for Ten Diagnostic Categories. Expectation from Equation (1), Disregarding Inherent Immunizability, and from Equation (2), Including Group Immunizability

DIAGNOSTIC CATEGORY	Number n	Observed Mean	Equation (1) Expected Mean	Equation (1) "Student's" t^*	Equation (2) Expected Mean	Equation (2) "Student's" t^{**}
Undiff. imbecility	44	2.49	2.50	—0.04	2.54	—0.43
Familial morons	31	2.65	2.55	+0.70	2.59	+0.43
Central nerv. syst. malformations	5	2.90	2.76	+0.41	2.77	+0.41
Epilepsy and other defects	6	2.60	2.27	+1.03	2.36	+0.83
Psychosis and mental deficiency	6	2.20	2.52	—1.03	2.56	—1.26
Post-traum. idiocy	6	2.82	2.66	+0.49	2.72	+0.32
Post-infect. idiocy	4	2.38	2.49	—0.30	2.55	—0.49
	102	2.56	2.52	+0.51	2.56	—0.09
Mongoloids	21	2.08	2.49	$\underline{-2.04}$	2.07	+0.05
Dysendocrines	5	3.18	2.23	$\underline{\underline{+2.52}}$	3.15	+0.11

$$^{*}t^2 = \frac{(\text{Obs-Exp})^2 n}{0.5907} \qquad ^{**}t^2 = \frac{(\text{Obs-Exp})^2 n}{0.5011}$$

Table 5 shows the observed and expected group mean for ten major categories which were classified by the medical staff of the institution, before the immunization program started.

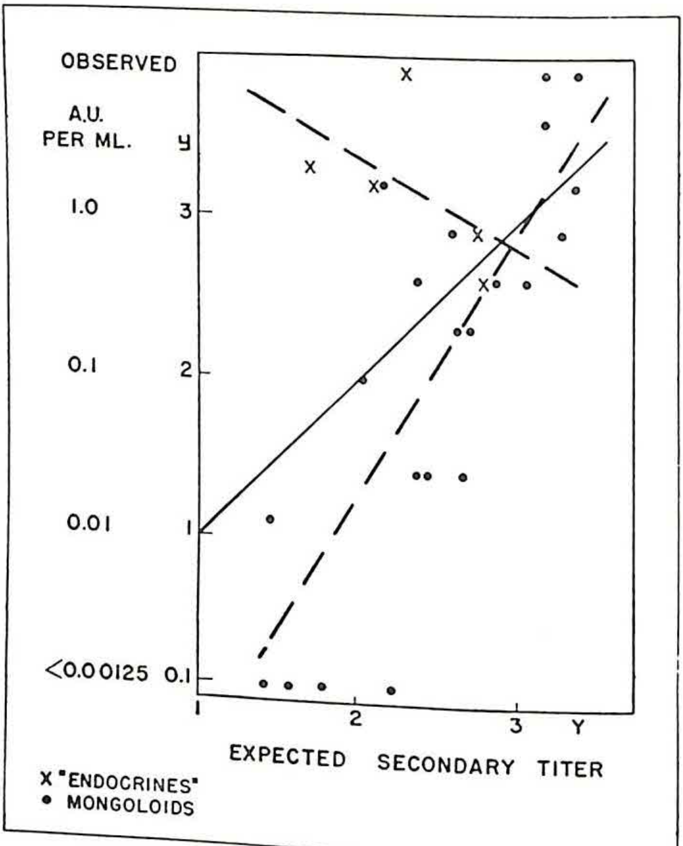

FIG. 3. OBSERVED RESPONSES OF 21 MONGOLOIDS AND 5 "DYSENDOCRINES" IN RELATION TO VALUES EXPECTED FROM EQUATION 1

While the observed titers of eight categories, composing 102 persons, agree well with expectancy equation (1), there are two groups which deviated to the borderline of significance. Mongoloids (21 persons) have a too low response, and "dysendocrines" (5 persons) show an excessive response.

A further analysis of the deviations from expected values within the two groups show that deviations are largest from low expectancies, while high expectancies give acceptable fits.

That mongoloids have less immune response than other individuals is evidenced in studies by Siegel ('48). The group "dysendocrines" is not a well defined one but since it seems to represent an immunological antipode to the mongoloids, it is worth including it in an analysis of immunizability.

Since the two abnormal groups have approximately the same numerical deviation, the immunizability can be tested as a linear regression by assigning the factorial $x_1 = +1$ to the dysendocrines, $x_1 = -1$ to the mongoloids, and $x_1 = 0$ to the remainder categories. The matrix of table 3 contains the significant components; others were also tested, such as the interaction x_1x_2 without giving additional information. The significance of the factor x_1 and its interaction with z is brought out in the analysis of variance. Table 4.

With the solutions of the regression coefficients the expectancy equation now takes the form:

$$y = 1.549 + 0.636x_2 + 1.001z - 0.435x_2z + 1.197x_1 - 0.872x_1z \cdots \quad (2)$$

Equation (2) can be rearranged in the form:

$$y = 1.549 + 0.636(1.88x_1 + x_2) + 1.001z - 0.435z(2.00x_1 + x_2) \cdots \quad (3)$$

which indicates that the inherent factor x_1 has about equal additive effects to the dual functions of the primary dose x_2: one of increasing the secondary response, the other of decreasing the regression of the secondary dose z on the response.

The different contribution of the primary dose and of the immunizability is clearly shown in Figure 4 which presents the observed data in relation to the expected regression lines of y and z for four groups.

The upper line represents the expectancy for the 5 dysendocrines who received an average primary dose of $x_2 = 0.76$, which inserted in equation (2) together with $x_1 = 1$, gives

$$y = 3.26 - 0.200z \cdots \quad (4)$$

The lowest line represents the equation for the mongoloids, where $x_2 = 0.67$ and $x_1 = -1$ leading to

$$y = 0.719 + 2.162z \cdots \quad (5)$$

The two intermediate lines are the expectancy for two primary dose levels of the 102 "normals," of which the upper is the expectancy for 47 individuals with relative high primary dosage ($x_2 = 1.14$) and the lowest line represents 55 persons with a lower primary dose ($x_2 = 0.33$).

The equations are, respectively:

$$y = 2.274 + 0.505z \cdots \tag{6}$$

and

$$y = 1.759 + 0.857z \cdots \tag{7}$$

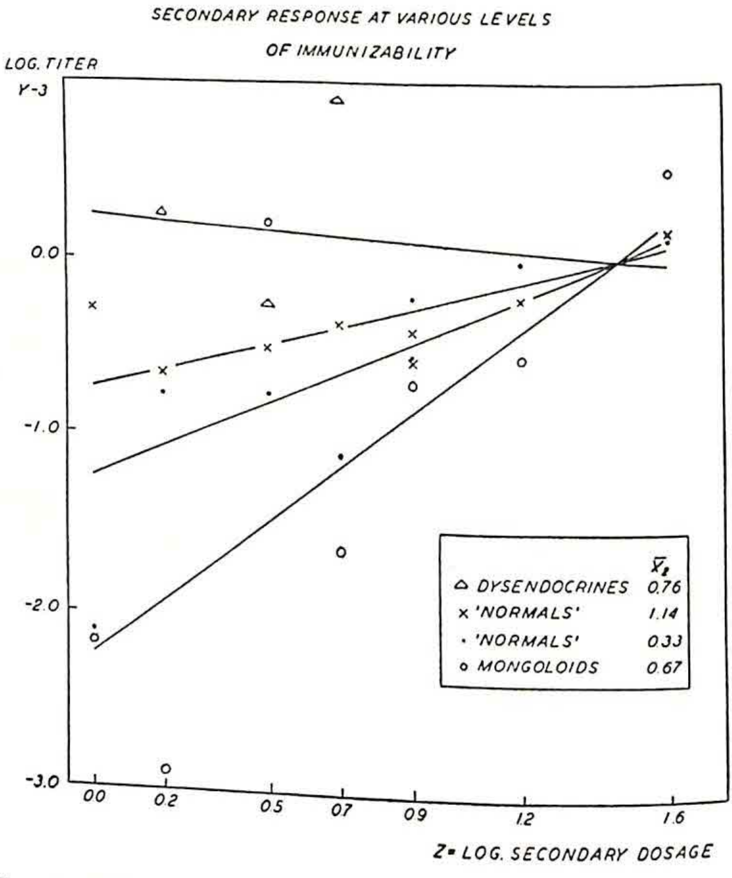

FIG. 4. SECONDARY RESPONSE OF THE VARIOUS IMMUNITY LEVELS, RELATED TO SECONDARY DOSE

The difference between the two "normal" groups is much less pronounced than the difference between the mongoloids and dysendocrines who had approximately the same primary dosage. The points represent the mean of 1-8 individuals of the same kind and with same secondary dosage.

DIFFERENCE IN IMMUNIZABILITY AT PRIMARY STIMULUS

The difference in the two somatic groups amount to about $2 \times 1.88 = 3.76$ in terms of log. primary dose as estimated from the secondary response (equation (3)). This means that the mongoloids would need about 5600 times more potent primary stimulus than the dysendocrines in order to obtain the same responsiveness to secondary stimulus.

This difference is in contrast to the difference in inherent immunizability which can be estimated from the primary response.

The following data are available for the response (v) of the three groups after the first injection, and are presented in table 6.

TABLE 6

Primary Response in Three Groups of Different Immunizability

Group	Number	Average Primary Dosage	Percent with Measurable Antitoxin	Mean Primary Response ($\bar{v}$)
" Normals "	102	0.77	41.2%	0.521
Mongoloids	21	0.67	23.8%	0.229
Dysendocrines	5	0.76	60.0%	0.880
Difference in Immunizability Mongoloids vs. Dysendocrines (in terms of primary dosage)			0.35 ± 0.31	0.79 ± 0.40

The difference in primary response is noticeable, but hardly significant, and even with the large error involved, the difference is nowhere near the extreme difference of 3.76 found from the secondary response of the two groups.

This discrepancy between estimates of immunizability obtained by primary and by secondary response needs further study, which we are now pursuing in inbred mouse strains. (Ipsen, '53B).

RELATION OF PRIMARY RESPONSE TO SECONDARY RESPONSE

The foregoing analysis showed that information of both inherent immunizability and of the primary immunization is necessary to form estimates of the response to a certain secondary dose.

The question now arises whether the primary response gives enough information of both the primary dose and the inherent immunizability, so that the primary response can be used as an efficient covariance to the secondary response.

The procedure used in the analysis was the same as used above, only the primary response (v) is used instead of the primary dosage (x_2).

Those primary titers which were below the limit of measurement were assigned the value 0.1 (as indicated in table 1).

The matrix of sums necessary for the multiple regression analysis is found in table 3. The solutions of the regression coefficients and the means lead to the following expectancy equation:

$$y = 1.747 + 0.567(v + 2.07x_1) + 0.917z - 0.497z(v + 1.74x_1) \cdots \quad (8)$$

This equation has almost the same form as equation (3) with insignificant difference between the coefficient of x_2 and v. It is particularly noteworthy that the coefficients of x_1 are of the same magnitude in both equations. The analysis of variance (table 4, lower part) shows that x_2 and v give almost equivalent information, while the components of x_1 are of same order of magnitude.

In other words, a given primary antitoxin titer reflects the amount of previous exposure to antigen but it does not predict the full extent of the response to a secondary stimulus.

Since only 50 of 128 individuals had measurable antitoxin after the first dose, it is possible that the relationship expressed in equation (8) is biased because of the large number of v values which have been assessed the limit value of 0.1.

In those persons where the primary titer can be measured, the effect of the inherent immunizability might be included in the primary titer. However, the equation obtained with these 50 individuals has the form:

$$y = 1.61 + 0.72(v + 1.80x_1) + 1.27z - 0.82z(v + 1.34x_1) \cdots \quad (9)$$

which is not significantly different from equation (7) obtained from all 128 samples.

The analysis of variance (table 4) shows that the components due to x_1 are at least as important as those due to v. Hence, it is concluded that inherent immunizability is a function which is independent of the primary response.

DISCUSSION

In the attempt to analyse the variables which influence the secondary response, the procedure has been restricted to analysis of linear components. The true functional equations are probably exponential functions with curves tending toward asymptotes at high values of the respective variables. Such functions are not amenable to explicit regression analysis, and no increase in information was obtained by adding higher terms of a polynomial expansion. The three measurable variables:

(z) potency of secondary dosage

(x_2) potency of primary dosage

(v) antitoxin before secondary immunization

were all found to have some relation to the secondary response. The correlation, however, vanishes at high values of all or either of the variables.

It was further possible to recognize two somatic groups of individuals which deviated from the general expectancy in positive and negative directions, respectively. This discrepancy is ascribed to inherent factors, termed immunizability. While the primary response barely disclosed deviating immunizability, the factor was significantly noticeable after secondary stimulus.

Because of the inhomogeneous character of the population used in this study it is highly likely that other individuals than the dysendocrines and the mongoloids have deviating inherent immunizability; however, these groups were the only ones which could be separated *a priori* on the basis of the available information. Other categorization, such as blood type, was tried with no result.

Bio-assays based on secondary response are feasible, but they meet more obstacles than assays based on primary response.

The restrictions are:

1. Small secondary doses only will give significant regression of response on dose. What should be classed "small dose" depends on the animal species used. In men, such doses are of reasonable magnitude, which appears from this study of tetanus toxoid and from that of Edsall, Banton and Wheeler ('51) who worked with small secondary doses of diphtheria toxoid.

2. Individuals with high immunity status give less significant response, i. e., rise in titer after the secondary dose.

3. Individuals with no measurable immunity may be of two categories, previously immunized or not immunized. These inseparable categories yield widely different results, and immunization histories are necessary for efficient interpretation.

4. Inhomogeneity of the group with regard to immunizability introduces an important variable, which can rarely be determined *a priori*, except in pure inbred animal strains. This variable is most distinct after secondary stimulus.

ACKNOWLEDGEMENT

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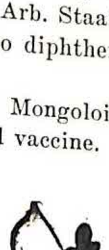

INBREEDING COEFFICIENTS OF THE RAMAH NAVAHO POPULATION

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INTRODUCTION

ANY discussion of inbreeding should distinguish between two senses in which the term has been used: the social, and the biological. Socially speaking, we may refer to *endogamic* mating, that is, to mating which occurs within the limits of a socially-defined category, such as a community, a clan, a caste, or a class. Biologically speaking, *inbreeding* refers to the mating of individuals with one or more common biological ancestors. Inbred individuals are offspring of genetic relatives and inbreeding is the mating of genetically related individuals.

The genetic consequences of inbreeding and endogamy may differ. Relatively small, endogamous and isolated human populations are not necessarily highly inbred. The degree of inbreeding in many natural and enduring local populations is slight compared to that characteristic of matings typical for some domestic and experimental animals.

Throughout the remainder of this paper we shall be concerned with inbreeding in the biological sense, and not, except as noted, with endogamy in the social sense.

This paper describes the types, and gives a measure of the degree, of inbreeding in the Ramah Navaho population as of September first 1948. A number of estimates of inbreeding coefficients based on various sorts of cousin marriages are available for human populations (see the summary in Neel, et al., '49). Measurements of inbreeding for relatives of all degrees, for a total human population seemingly have not been published heretofore.

INBREEDING COEFFICIENTS

Wright ('22) developed a coefficient of inbreeding that gives (for a population) the departure toward complete homozygosity from the heterozygosity expected under a system of random mating. This coefficient is a direct measure of the average effects on zygosity due to inbreeding expected from the pattern of mating in any given pedigree, population, or population segment. Wright's coefficient has the great advantage (not present in others, e. g., those of Pearl, '13, nor Krizenicky, '23) that the degree of inbreeding in an observed genealogy, however complex or irregular the pattern of mating, may be compared to that observed or expected under any regular system of inbreeding. In this way theoretical models, and the results of experiments, become useful for interpretation of human population data.

In analysis of the Ramah Navaho data, we found it convenient to use the following definition of the inbreeding coefficient, *i*, identical with that of Wright ($i_0 \equiv f_0$):

$$i_0 = \Sigma(1/2)^{n-1}(1 - i_A),$$

where n is the number of steps (the path from parent to offspring) in a *loop* of descent closing on an inbred individual 0, i_A is the i of a common ancestor A, and summation is over all loops terminating in 0. If A is not inbred, the coefficient is reduced to

$$i_0 = \Sigma(1/2)^{n-1}.$$

The quantity i_0 may be considered as the probability that an inbred individual with one given autosomal gene will possess two genes of common origin at the given locus. Also, i_0 may be defined as the most likely fraction of all gene pairs to consist of homozygous pairs. It is important to emphasize that the coefficient as used here is relative to the average zygosity of a random-bred population. If p is the frequency of a gene, and $(1 - p) = q$ is the frequency of its allele, the average heterozygosity of a population for the pair of alleles at equilibrium will be $2pq$. The value of p and q, of course, may vary with different gene pairs in the same population. The population effect of inbreeding on zygosity is to make the proportion of heterozygotes $< 2pq$, and thus, the proportion of homozygotes $> p^2 + q^2$.

Something of the genetic meaning of i_0 is illustrated in figure 1 where AA' represents the genotype of a common ancestor. The probability that this ancestor will pass gene A to his child is 1/2. Likewise, the probability that he will pass gene A' is 1/2. Now gene A may pass to 0 by the left side of the loop with a probability $(1/2)^3$, or by the right side with a probability $(1/2)^2$. Thus the probability that 0 will be of homozygous genotype AA is $(1/2)^5$. But gene A' may pass over the same two paths (and 0 be of genotype $A'A'$) with equal probability—thus the factor 2 in the coefficient:

$$i_0 = 2\sum[(1/2)^3 + (1/2)^2] = 2(1/2)^5.$$

Or, in more general terms,

$$i = 2\sum[(1/2)^{n_L} + (1/2)^{n_R}] = 2\sum(1/2)^n = \sum(1/2)^{n-1}$$

where n_L is the number of steps in the left side of the inbreeding loop, n_R the number in the right side, and $n = n_L + n_R$.

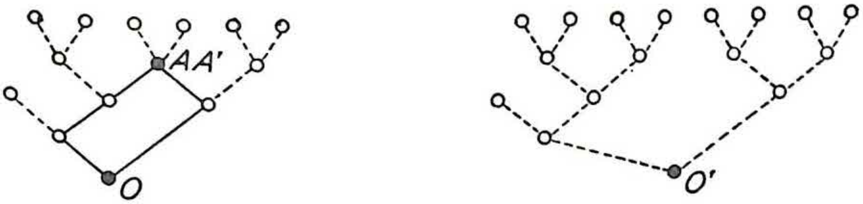

FIG. 1. DIAGRAMS TO ILLUSTRATE THE GENETIC BASIS OF THE INBREEDING COEFFICIENT. IN THE PEDIGREE ON THE LEFT INDIVIDUAL 0 IS INBRED; IN THE PEDIGREE ON THE RIGHT INDIVIDUAL 0′ IS NOT INBRED

The derivation and genetic significance of $i_0 = f$ is discussed in detail by Wright ('22, '51), Li ('48), and Ludwig ('44). Wright derived the coefficient of inbreeding (f) by the method of path coefficients. Bernstein's ('30) coefficient, α, is identical with f of Wright. Haldane and Moshinsky ('39) give an algebraical derivation. Malécot ('48) has shown that the general formula for f may be obtained directly from probability theory. Using matrix methods, Fisher ('49) has proposed an inbreeding statistic which is identical with $[-\log_e(1-f)]$.

In the method of Haldane and Moshinsky, the relationship of fathers and mothers (parents of the inbred individuals in question) is classified for each inbreeding loop connecting the parents and the inbred individual 0, and the value of i_0 is found by such expressions as: for full r-th cousins s times removed $i_0 = 2^{-2r-s-2}$, and for half r-th cousins s times removed $i_0 = 2^{-2r-s-3}$, the values of the i_0 being summed over all inbreeding loops that contain 0.

Calculation of the inbreeding coefficient is illustrated in figure 2 which is the pedigree of the most highly inbred sibship of the Ramah Navaho population. In this pedigree 6 different inbreeding loops connect 0 and his 6 different common ancestors. The value of i_0 for each of the 6 loops is shown in the figure, their sum totaling .0977. This

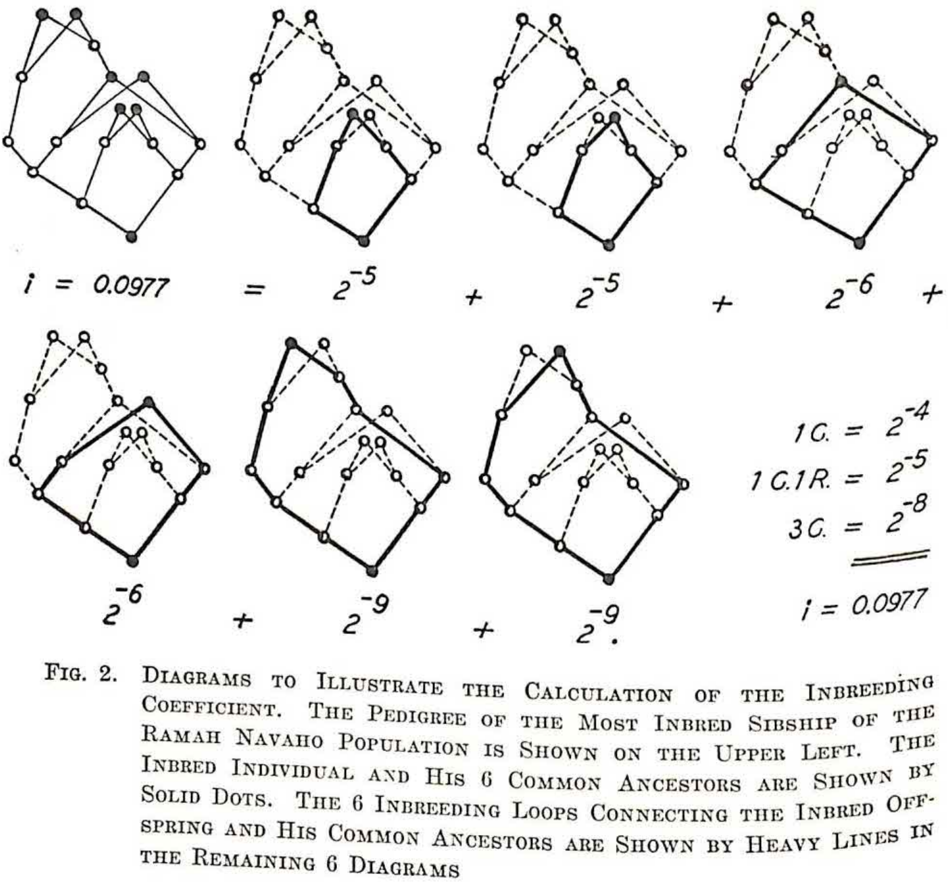

FIG. 2. DIAGRAMS TO ILLUSTRATE THE CALCULATION OF THE INBREEDING COEFFICIENT. THE PEDIGREE OF THE MOST INBRED SIBSHIP OF THE RAMAH NAVAHO POPULATION IS SHOWN ON THE UPPER LEFT. THE INBRED INDIVIDUAL AND HIS 6 COMMON ANCESTORS ARE SHOWN BY SOLID DOTS. THE 6 INBREEDING LOOPS CONNECTING THE INBRED OFFSPRING AND HIS COMMON ANCESTORS ARE SHOWN BY HEAVY LINES IN THE REMAINING 6 DIAGRAMS

value is a measure of the degree of inbreeding of individual 0. The value may be checked by classifying the relationship of 0's father to 0's mother and summing the values of i_0 for each type of relationship, following the method of Haldane and Moshinsky. The parents of 0 are related in three different ways: 1) full first cousins, $i_0 = 2^{-4}$, 2) full first cousins once removed, $i_0 = 2^{-5}$, and 3) full third cousins, $i_0 = 2^{-8}$, the sum of these values being .0977.

The above remarks on the inbreeding coefficient assume that the alleles concerned are autosomal. Roughly 95% of human gene loci are autosomal, the remaining 5% being sex-linked, holandric, and partially sex-linked, (Spuhler, '48). Haldane and Moshinsky ('39) and Wright ('51) have extended the definition of the inbreeding coefficient to cover these non-autosomal loci. Calculations of the inbreeding coefficient for sex-linked genes have been made for the Ramah population and will be presented in a later paper. The data of the present paper pertain to autosomal genes only.

THE RAMAH NAVAHO POPULATION

The Ramah Navaho are a local group of Navaho Indians residing in the vicinity of Ramah, west central New Mexico. The Navaho are an Athabascan-speaking people who have lived in the American Southwest since at least 1,000 A. D. Unlike the Anglo-American, Spanish American and Pueblo peoples of the area, the Navaho do not concentrate their population into villages. Rather, the community is composed of biological families (or more usually such families combined into extended families with matrilineal descent and matrilocal residence) widely spaced in groups of small houses or hogans. The Navaho subsistence pattern is a combination of sheep-husbandry and dry-farming agriculture. The closest Anglo-American towns are Gallup, 42 miles distant and about 11,000 in population, and Grants, 60 miles away and 3,000 in population.

Kluckhohn and Leighton ('46) give an introduction to the anthropology of the Navaho, with some emphasis on the Ramah people; Kluckhohn and Spencer ('40) provide a comprehensive bibliography of the Navaho literature up to 1940.

The group at Ramah was founded about 1820 when a few families moved into the area to hunt and farm. They were preceded there by the village-dwelling Zuni Indians, but they occupied the area before the present Spanish American, Mormon and "Texan" settlements were established. The Ramah group was reestablished soon after the Navaho returned from U. S. Army captivity at Fort Sumner, New Mexico, that is, in the decade 1870-1880.

The Ramah population is isolated geographically from the larger concentrations of Navaho in northwestern New Mexico and northeastern Arizona. The Ramah group lives in an area of about 18 by 29 miles including some 505 square miles of which about 230 are Navaho-controlled. Three other Navaho communities are in the general region, one 25 miles to the north, one about 50 miles to the east, and one about 75 miles to the southeast. There has been some biological interchange between the Navaho local groups.

On September first 1948 the Ramah group totaled 614 individuals, giving a Navaho population density of around 1.22 persons per square mile. Roughly 600 non-Navaho individuals occupy the same area (mostly Anglo-Americans, Spanish Americans, and Zuni Indians) with a total population density of about 2.40 persons per square mile (see, for brief additional information, Kluckhohn and Griffith, '51).

CULTURAL FACTORS IN NAVAHO MATE SELECTION

The explicit cultural regulations on Navaho marriage are mainly defined negatively. Thus in the case of the Ramah Navaho, one may not marry:

1) a member of one's own clan,
2) a member of one's father's clan,
3) a member of a clan "linked" to one's own clan,
4) a member of a clan "linked" to one's father's clan.

The Ramah genealogies show 4 violations (out of 399 known marriages) of the first prohibition, 5 of the second. Transgression of the third and fourth regulations are more frequent but cannot be enumerated exactly because of disagreement among the Navaho themselves as to which of the clans should be considered "linked." In any case violations of these types are not as such biologically significant except perhaps at quite remote generations for which precise data are not available.

The existence of matrilineal exogamous clans among the Ramah Navaho does make for outbreeding, both because marriage with first cousins on either side is specifically forbidden (but 4 sibships in the population have been produced by first cousin matings) and because, at Ramah, all members of the same clan (with a few exceptions) can be shown to be genetic relatives. In general, it may be said that the effect of clan and clan-group exogamy is toward a wide selection of mates within the local population and toward the procurement of mates from outside communities. It tends toward forcing genes from other Navaho groups, other Indian tribes, Spanish Americans, and Anglo-Americans to be spread widely (and, in the Ramah case, thinly) in the population.

(Of the 317 fertile matings shown in the genealogies, 35 or 11.1% involve a mate from outside the Ramah population.) To some extent also, the cultural interferences with mating tend to cancel one another.

Clan membership may turn out to have other consequences for the genetic composition of this population which we are not prepared to demonstrate at present but which we hope to treat in later papers. We now call attention merely to the varying numerical composition of Ramah clans and to the fact that marriage between clans does not occur at random.

Of individuals in the genealogies whose clan membership (or non-Navaho affiliation) is definitely ascertained, 77% are included within the 4 largest clans in this area, 97% are included within the 6 largest (see Kluckhohn and Griffith, '51, p. 405 ff., for a survey of the composition as of September first 1948; data presented in that paper and in the present section overlap but also supplement one another). That is, all marriages of individuals from 15 additional clans plus those of a Yaqui Indian, a Walapai, a Laguna, a Spanish American, an Anglo-American, and 8 Chiricahua Apaches account for only 3% of the total marriages.

TABLE 1

322 Ramah Navaho marriages classified by clan membership of the spouses

Clan	B	C	D	E	F	G	H	I	Total
A	31	39	26	21	14	6	2	9	148
B	–	25	31	10	8	2	1	6	83
C		–	15	4	7	5	–	16	47
D			4	10	9	2	–	7	32
E				–	8	1	–	3	12
Total	31	64	76	45	46	16	3	41	322

Of 399 known marriages (317 of these produced sibships and are analyzed for inbreeding in this paper) almost 88% are included within marriages of members of the 5 most numerous clans with each other and with members of 4 additional clans. Table 1 shows certain preferential tendencies for clans to exchange members in ways not determined by the system of linked clan exogamy. For example, 24% of the marriages of clan A members are with clan C members, whereas 14% is expected on a random basis in proportion to numbers of available adults. Preference is even more striking in the case of the 16 matings of clan C with clan I members. The clan I column has another interest in that it is not a "native" Ramah clan. These marriages, except for two in the founding generation, represent the securing of mates from other Navaho groups.

Additional cultural factors in mating, though not explicit regulations, are: permissible stepdaughter marriage (5 known cases in the history of this population); permissible polygyny with strong preference for sororal polygyny; easy tolerance of divorce and re-marriage and indeed minimal interference with sexual activities not constituting culturally defined "incest"; some practice of the levirate and sororate; approval of cross-generational marriages in both directions—i. e., older women also marry younger men with some frequency; tendency for repeated exchanges between biological or extended families in marriages (e. g., a man is more likely to marry the sister of his brother's wife or cousin's wife or the sister of his sister's husband).

THE DATA

Our calculations of inbreeding coefficients have been made from data summarized on a large genealogical chart showing the relationship and matings of 1118 members of the population during 8 generations (counting the initial, "founding" generation as one). The time period covered by the genealogies—as opposed to the present outbreeding population which has existed as such only since about 1870-1880—is from about 1820 to September first 1948. This genealogical chart was compiled by Clyde Kluckhohn, Katherine Spencer, and J. N. Spuhler, and drawn by Ann Tulloch. (Unfortunately, the chart is too large to reproduce with this paper; copies are on deposit in the Peabody Museum, Harvard University, and the Institute of Human Biology, University of Michigan.) The population data basic to the Ramah Navaho census and the genealogical chart were collected and worked up by members of the Ramah Project of Harvard University, especially Clyde Kluckhohn, Katherine Spencer, Janine Chappat Rosenzweig, and Nan Stoller. Individual pedigree charts (similar to that shown in figure 2) were traced by Helen Spuhler on a separate card for each inbred sibship in the population and these cards were used to calculate the coefficients for each inbred mating.

RAMAH NAVAHO MATING TYPES

Table 2 is a summary of the incidence of 62 different mating types observed in the Ramah population. Sixty-one of these mating types involve inbreeding, and of these 17 types involve matings where the parents are related in a single way, 44 types involve matings where the parents are related in two or more ways.

TABLE 2

Incidence of 62 mating types by sibship and siblings for 4 generations of the Ramah Navaho Population. See text for details.

RELATION OF MATES				GENERATION								Totals		% of pop. i_0
				5		6		7		8				
		p	i_0	S	I	S	I	S	I	S	I	S	I	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
1.	F1C	4	.0625	–	–	1	6	–	–	–	–	1	6	5.076
2.	HNeGA	5	.0312	–	–	1	5	–	–	–	–	1	5	2.112
3.	GUHNi	5	.0312	–	–	–	–	1	7	–	–	1	7	2.956
4.	F1C1R	5	.0312	3	22	–	–	–	–	–	–	3	22	9.291
5.	H1C1R	6	.0156	–	–	–	–	1	9	–	–	1	9	1.900
6.	F2C	6	.0156	3	16	5	32	1	1	–	–	9	49	10.347
7.	DF2C1R	6	.0156	1	1	2	16	–	–	–	–	3	17	3.590
8.	H2C	7	.0078	–	–	–	–	1	1	–	–	1	1	0.106
9.	F2C1R	7	.0078	–	–	7	27	2	7	–	–	9	34	3.590
10.	H2C1R	8	.0039	4	19	–	–	–	–	–	–	4	19	1.003
11.	F2C2R	8	.0039	–	–	–	–	1	4	–	–	1	4	0.211
12.	F3C	8	.0039	–	–	3	16	5*	9	–	–	8*	25	1.320
13.	H2C2R	9	.0020	–	–	1	5	–	–	–	–	1	5	0.135
14.	H3C	9	.0020	1	5	2	8	2	5	–	–	5	18	0.487
15.	F3C1R	9	.0020	–	–	1	1	6	14	–	–	7	15	0.406
16.	H3C1R	10	.0010	1	5	1	8	–	–	–	–	2	13	0.176
17.	H4C	11	.0005	–	–	–	–	1	3	–	–	1	3	0.020
18.	F1C F1C1R F3C	4 5 8	.0977	–	–	–	–	1	8	–	–	1	8	10.580
19.	F1C F2C1R	4 7	.0703	–	–	1	1	–	–	–	–	1	1	0.952
20.	F1C H4C H4C1R	4 11 12	.0632	–	–	–	–	1	2	–	–	1	2	1.711
21.	F1C1R F2C2R	5 8	.0352	–	–	–	–	1	1	–	–	1	1	0.476
22.	F1C1R F3C	5 8	.0352	–	–	–	–	2	3	–	–	2	3	1.429

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* Includes one child of uncertain paternity.

TABLE 2—*Continued*

RELATION OF MATES (1)	(2)	p (3)	i_0 (4)	GENERATION 5 S (5)	5 I (6)	6 S (7)	6 I (8)	7 S (9)	7 I (10)	8 S (11)	8 I (12)	Totals S (13)	Totals I (14)	% of pop. i_0 (15)
23.	H1C1R	6	.0352	–	–	–	–	1	1	–	–	1	1	0.476
	F2C2R	8												
24.	F1C1R	5	.0703	–	–	–	–	2	4	–	–	2	4	3.806
	H1C1R	6												
	F2C	6												
	F3C	8												
	F3C1R	9												
	DF4C	9												
25.	F1C1R	5	.0547	–	–	–	–	1	5	–	–	1	5	3.702
	H1C1R	6												
	DF3C	7												
26.	H1C1R	5	.0488	–	–	–	–	1	1	–	–	1	1	0.660
	F2C	6												
	DF4C	9												
27.	H1C1R	6	.0273	–	–	3	14	–	–	–	–	3	14	5.173
	F2C1R	7												
	F3C	8												
28.	H1C1R	6	.0278	–	–	2	2	2	10	–	–	4	12	4.516
	F2C1R	7												
	H3C	9												
	F3C1R	9												
	DH4C1R	11												
29.	H1C1R	6	.0264	–	–	1	5	1	3	–	–	2	8	2.859
	F2C1R	7												
	H3C	9												
	DH4C	10												
30.	H1C1R	6	.0244	–	–	1	2	–	–	–	–	1	2	0.660
	F2C1R	7												
	H3C1R	10												
31.	H1C1R	6	.0234	–	–	–	–	1	1	–	–	1	1	0.317
	F3C	8												
	DF3C1R	8												
32.	F2C	6	.0234	–	–	1	1	–	–	–	–	1	1	0.317
	F2C1R	7												
33.	DF2C	5	.0391	–	–	1	7	–	–	–	–	1	7	3.705
	F2C1R	7												
34.	F2C	6	.0242	–	–	–	–	1	1	–	–	1	1	0.328
	H2C1R	8												
	DF3C1R	8												
	H4C	11												
	H4C1R	12												

TABLE 2—*Continued*

RELATION OF MATES		p	i_0	GENERATION 5		6		7		8		Totals		% of pop. i_0
				S	I	S	I	S	I	S	I	S	I	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
35.	F2C F3C F3C1R	6 8 9	.0215	–	–	1	1	2	8	–	–	3	9	2.619
36.	F2C DF3C H3C F3C1R H4C H4C1R	6 7 9 9 11 12	.0281	–	–	1	3	–	–	–	–	1	3	1.141
37.	F2C H2C H3C	6 7 9	.0254	–	–	1	4	–	–	–	–	1	4	1.375
38.	F2C H2C H3C F3C1R FC4	6 7 9 9 10	.0283	–	–	–	–	–	–	1	2	1	2	0.766
39.	H2C F3C	7 8	.0117	–	–	–	–	2	7	–	–	2	7	1.109
40.	H2C DF3C	7 7	.0156	–	–	–	–	1	1	–	–	1	1	0.211
41.	H2C F3C F3C1R H3C1R F4C F4C1R H4C	7 8 9 10 10 11 11	.0166	–	–	–	–	–	–	1	3	1	3	0.674
42.	H2C F2C1R H3C F4C	7 7 9 10	.0186	–	–	–	–	1	1	–	–	1	1	0.252
43.	H2C F3C1R H4C H4C1R	7 9 11 12	.0105	–	–	–	–	1	1	–	–	1	1	0.142
44.	F2C1R F3C	7 8	.0117	–	–	2	6	–	–	–	–	2	6	0.950
45.	F2C1R F3C H3C	7 8 9	.0137	–	–	1	3	–	–	–	–	1	3	0.556
46.	F2C1R H3C H3C1R	7 9 10	.0107	–	–	1	1	–	–	–	–	1	1	0.145

TABLE 2—*Continued*

RELATION OF MATES		p	i_0	GENERATION 5		6		7		8		Totals		% of pop. i_0
(1)	(2)	(3)	(4)	S (5)	I (6)	S (7)	I (8)	S (9)	I (10)	S (11)	I (12)	S (13)	I (14)	(15)
47.	F2C1R F3C1R	7 9	.0098	–	–	1	3	–	–	–	–	1	3	0.398
48.	F2C1R H4C	7 11	.0083	–	–	2	7	–	–	–	–	2	7	0.786
49.	F2C2R H2C1R F3C1R H4C1R	8 8 9 12	.0100	–	–	–	–	–	–	1	3	1	3	0.406
50.	H2C1R F3C1R	8 9	.0059	–	–	–	–	7	19	–	–	7	19	1.517
51.	H2C1R H3C1R	8 10	.0049	–	–	–	–	1	2	–	–	1	2	0.133
52.	F3C H4C	8 11	.0044	–	–	–	–	1	1	–	–	1	1	0.060
53.	F3C H4C1R	8 12	.0042	–	–	–	–	1	2	–	–	1	2	0.114
54.	H3C H3C1R	9 10	.0029	–	–	1	1	–	–	–	–	1	1	0.039
55.	H3C F4C	9 10	.0029	–	–	–	–	2	5	–	–	2	5	0.196
56.	F3C1R H4C1R	9 12	.0022	–	–	–	–	1	2	–	–	1	2	0.060
57.	H3C1R H4C	10 11	.0015	–	–	1	6	–	–	–	–	1	6	0.122
58.	H2C DF3C1R H3C1R	7 8 10	.0127	–	–	–	–	1	1	–	–	1	1	0.172
59.	H2C H3C F4C	7 9 10	.0107	–	–	–	–	1	1	–	–	1	1	0.145
60.	H2C F3C H3C F4C	7 8 9 10	.0146	–	–	–	–	–	–	2	3	2	3	0.593
61.	H1C1R F2C F3C1R F4C	6 6 9 10	.0342	–	–	–	–	–	–	1	2	1	2	0.926
Totals, inbred matings				13	68	46	191	58	151	6	13	123	423	100.000
62.	" Unrelated "		0	47	204	68	223	39	68	1	1	155	496	
Totals, all matings				60	272	114	414	97	219	7	14	278	919	

In column 1 of table 2 a serial number is assigned to the various mating types. Column 2 gives the "relation of mates" for each type. The following abbreviations are used in this column:

A — Aunt
C — Cousin
D — Double
F — Full
G — Great
H — Half
Ne — Nephew
Ni — Niece
R — Removed
U — Uncle
1 — First (or, preceding R, Once)
2 — Second (or, preceding R, Twice)
3 — Third
4 — Fourth

For example, "DH4C1R" means "*D*ouble *H*alf *F*ourth *C*ousins *O*nce *R*emoved."

Column 3 gives the power (p) of the exponent fixing the contribution of each *type of parental relationship* to the inbreeding coefficient. For example, F1C (Full First Cousins) contribute $(1/2)^4$ to the coefficient (as explained above).

Column 4 gives the contribution for autosomal loci of each *type of mating* to the coefficient. This is the sum of (p) over each of the various sorts of relationship (or, over each inbreeding loop) between the mates involved in each mating. For example, in mating type 18, $i = 0.0977$, which is the sum of $(1/2)^4 + (1/2)^5 + (1/2)^8$.

Columns (5-12) in table 2 give the incidence of inbreeding by sibships (S) and by individuals (I) in generations 5, 6, 7, and 8 of the Ramah population together with the totals (columns 13-14) for each mating type, and the proportion (column 15) which each inbred mating type contributes to the population mean inbreeding coefficient.

Table 2, then, gives the distribution of all inbred individuals by mating type and generation. There are 123 inbred sibships containing 423 individuals. No inbreeding is known for generations 1 through 4 of the population, although the genealogies of the second, third, and fourth generations are established in fine detail. There are a total of 38(+) sibships with 199 offspring in generations 1-4. The number of sibships involved in the case of the 14 members of generation 1 is not exactly established.

Included in generations 5-8 are 496 "unrelated" individuals from 155 "outbred" sibships. There are, thus, a total of 278 matings of 62 different types in generations 5-8. These matings produced a total of 919 offspring.

TABLE 3

Inbreeding Coefficients of the Ramah Navaho Population

Generation	Number of Sibships	Number of Sibs	Number of Outbred Matings	Number of Outbred Sibs	Size of Outbred Sibships	Number of Inbred Matings	Number of Inbred Sibs	Size of Inbred Sibships	Range of Inbreeding Coefficient of Inbred Sibs	Mean Inbreeding Coefficient of Inbred Sibs	Mean Inbreeding Coefficient of Total Sibs
1	?	14	?	?	?	?	?	?	—	—	—
2	8	27	8	27	3.38	0	0	0	0	0	0
3	8	35	8	35	4.38	0	0	0	0	0	0
4	22	123	22	123	5.59	0	0	0	0	0	0
5	60	272	47	204	4.34	13	68	5.23	.0010-.0312	.0153	.0038
6	114	414	68	223	3.28	46	191	4.15	.0013-.0703	.0157	.0073
7	97	219	39	68	1.74	58	151	2.60	.0010-.0977	.0205	.0141
8	7	14	1	1	1.00	6	13	2.17	.0078-.0283	.0191	.0178
Inbred Sub-totals	–	–	–	–	–	123	423	3.44	.0010-.0977	.0175	—
Population Totals	316	1118	193	681	3.53	123	423	3.44	.0010-.0977	.0080	.0066

Table 3 is a summary by generation of the inbreeding coefficients of the Ramah population, with information on all generations since the founding of the population.

Some particular value of the inbreeding coefficient may have at least 4 different referents (Ludwig, '44; Wright, '51). It may refer to: (a) an individual, (b) the offspring of a given mating, i. e., a sibship, (c) a generation, or (d) a breeding population. Table 2 gives the raw data for determination of the first three of these sorts of referents. Table 3 summarizes this data in different form and gives information on outbred matings of generations 1-8.

Information is presented on 316 matings which produced 1118 offspring in 8 generations. 193 of these matings were outbred and produced 681 offspring. The remaining 123 matings were inbred and produced 423 offspring.

The range of the inbreeding coefficient for individuals (or full sibs) is .0010 to .0977. The mean coefficient for all *inbred* individuals for generations 5 through 8 is .0175. The mean coefficient for the population (generations 5 through 8 only) is .0080. The mean coefficient for the entire population since the foundation (generations 1 through 8) is .0066.

GRAPHICAL REPRESENTATION OF THE POPULATION

Homogeneous coordinates may be used to represent a Mendelian population (de Finetti, '27, Haldane and Moshinsky, '39). The frequencies of n genotypes which occupy a single autosomal locus may be represented by a point within a regular simplex in $(n-1)$ dimensional space where the perpendiculars of its n bounding planes are coordinates whose sum is unity. Thus the population frequencies of the three genotypes $(x\,AA + y\,Aa + z\,aa = 1)$ formed by a single pair of autosomal alleles, A and a, may be represented (fig. 3) by a point P in an equilateral triangle XYZ, where x, y, z are the perpendiculars from P on YZ, XZ, and XY respectively. If we let the gene frequencies of $A = p$, and of $a = (1-p) = q$, then $p = x - 1/2y$, and the points representing a population with a given gene ratio $(p:q)$ lie on the straight line PQ, where Q is the projection of P on XZ. The equations for $QZ = p$ are $x - 1/2y = p$, and $2qx + (q-p)y - 2pz = 0$.

Under a system of random mating, $x = p^2$, $y = 2pq$, and $z = q^2$, and the points generated by a parabola $y^2 - 4xz = 0$ (with vertex at the mid-point of the altitude of the triangle and with tangents to XY and

YZ at X and Z respectively) represent the genotype frequencies for autosomal single alleles in all possible ideally large random-mating populations.

Under a regular system of inbreeding the frequency of heterozygotes is reduced by a factor $(1 - i)$ where i is, of course, the inbreeding coefficient. Thus the frequencies of the three genotypes in regularly-inbred populations are $x = p^2 + ipq$, $y = 2(1 - i)pq$, and $z = q^2 + ipq$.

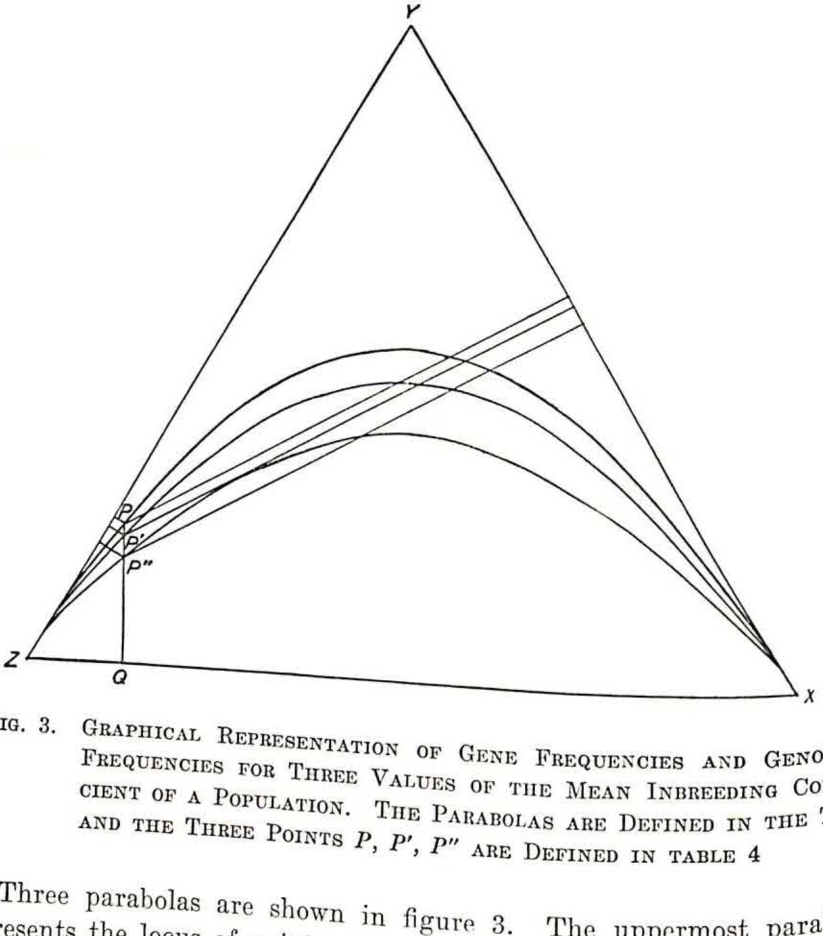

FIG. 3. GRAPHICAL REPRESENTATION OF GENE FREQUENCIES AND GENOTYPE FREQUENCIES FOR THREE VALUES OF THE MEAN INBREEDING COEFFICIENT OF A POPULATION. THE PARABOLAS ARE DEFINED IN THE TEXT AND THE THREE POINTS P, P', P'' ARE DEFINED IN TABLE 4

Three parabolas are shown in figure 3. The uppermost parabola represents the locus of points whose perpendicular coordinates measure the genotype frequencies for autosomal single alleles in a random-mated population. The middle parabola represents the locus of such points for the ideal case of a population practicing a regular system of inbreeding of such a degree that $i = .0977$. As shown above, this value is the maximum inbreeding coefficient observed for an individual Ramah

Navaho. The lowermost parabola represents the locus of points for a population following a regular system of full brother-sister mating for one generation.

The parabola representing the locus of points for a system of inbreeding where $i = .0080$ (the mean for generations 5 through 8 of the Ramah group) would lie below but very close to the parabola for a system of random mating. It follows that the distribution of autosomal genotype frequencies in the Ramah population would not be expected to show marked deviations from the proportion of heterozygotes expected under a system of random mating. We can illustrate this fact by considering the genotype frequencies for some particular gene frequency. Since the B gene (a^B) of the ABO blood group system is absent in the Ramah population, we may treat the $A(A)$ and $O(a)$ genes as a pair of single autosomal alleles. (The distribution of the MN blood types at Ramah will be considered in the following section.) The population frequencies of the AO genes based on a pooled sample of 458 individuals (Boyd and Boyd, '49; Mourant, '50) are $p = \bar{A} = .126$ and $r = \bar{a} = .874$ $(q = \bar{a}^B = 0)$.

TABLE 4

Genotype frequencies for 4 ideal systems of mating and the observed gene frequencies of ABO blood group genes of A and a in the Ramah Navaho population

Mating system	Inbreeding Coefficient, i_0	Group A $x\,AA$	$y\,Aa$	Group O $z\,aa$	Total
P	0	.016	.220	.764	1.000
P_{RN}	0.0066	.017	.218	.765	1.000
P'	0.0977	.027	.199	.774	1.000
P''	0.25	.043	.165	.792	1.000

The segment of the base of the triangle QZ represents the gene frequency p and the segment QX represents the gene frequency $(1 - p) = r$. The genotype frequencies in the population are determined jointly by these gene frequencies *and* the system of mating. We will consider four such systems. Three different mating systems are shown in figure 3 by points P, P' and P''. The fourth mating system is shown only in table 4 by point P_{RN} and indicates the appropriate genotype frequencies for a system of mating where the mean inbreeding coefficient is $i = .0066$. Inspection of the values in the graph and in the table indicates that the observed degree of inbreeding in the Ramah population would not be expected to bring about large deviations from the genotypical proportions theoretically appropriate for a system of random mating in the population.

INDIRECT ESTIMATE OF THE INBREEDING COEFFICIENT OF THE RAMAH POPULATION

Now that we have direct estimates of the inbreeding coefficient of the Ramah Navaho population, it is possible to compare the results with an estimate obtained by an indirect method. Haldane ('38) has shown that departures in the amount of heterozygosity from that expected under random mating can be interpreted to give evidence for the mating system in natural populations.

Consider a pair of autosomal alleles, such as the genes responsible for the MN blood types in man, where heterozygotes are distinguishable by phenotypical inspection. We will represent the three phenotypes by M, MN, and N, and their respective genotypes by MM, Mm, and mm. Let the observed phenotypical frequencies in the population be

$$a\,M + b\,MN + c\,N = n.$$

If the population was reproduced by random mating (with regard to the alleles M and m) and the gametes from the previous generation are represented by the proportion $u\,M : 1\,m$, the expected distribution of genotypes would be

$$nu^2/(u+1)^2\,MM : 2nu/(u+1)^2\,Mm : n/(u+1)^2\,mm.$$

The logarithm of the likelihood of the observation is

$$L = (2a+b)\log u - 2n\log(u+1).$$

Thus

$$dL/du = (2a+b)/u - 2n/(u+1) = 0,$$

and

$$u = (2a+b)/(b+2c) \pm \sqrt{2n(2a+b)/(b+c)^3}.$$

If this value of u is applied to the expected distribution of genotypes given above, the expected and observed numbers for each phenotype may be compared. A χ^2 test is appropriate.

If the differences between expected and observed values are too large to be consistent with a hypothesis of random mating, and the departure is in the direction of an excess of homozygotes, inbreeding is one of several possible explanatory factors. (In the case of the *MN* blood groups, probably we can safely exclude the possible explanatory factor of assortative mating.)

Bernstein ('30) found that expected ratios of the genotypes in an inbred population (with inbreeding coefficient i) are

$$(u^2 + iu) MM : 2(1 - i) u\, Mm : (iu + 1) mm.$$

Since the genotypes can be distinguished by serological tests, if we let, as above, the observed frequencies of phenotypes be

$$a\, M + b\, MN + c\, N = n,$$

then

$$u = (2a + b)/(b + 2c),$$

and

$$i = (4ac - b^2)/(2a + b)(b + 2c).$$

The observed distribution of the *MN* blood types in a sample of 458 Ramah Navaho (Boyd and Boyd, '49; Mourant, '50) is

$$380\, M + 74\, MN + 4\, N = 458$$

$u = 10.1707$, the expected distribution is

$$379.67\, M + 74.66\, MN + 3.67\, N = 458.00,$$

$\chi^2_1 = 0.0358$, and $0.8 < P < 0.9$.

Although the departure of the observed distribution from the expected values is in the direction of an increase in the proportion of homozygotes, that is, in the direction expected for an inbred population, the observed values are fully consistent with the hypothesis of random mating. But, as shown in the preceding section, the observed mean value of the inbreeding coefficient for the Ramah population is sufficiently small, and has been in effect for a sufficiently short period of time, that large deviations from the theoretical proportions appropriate for random mating are not to be expected. With this in mind, and noting that gene m is relatively rare in the population and that estimates of its frequency are subject to considerable fluctuation in small samples, it remains of interest to solve for the inbreeding coefficient. We find $i = .0088$. This indirectly obtained value is remarkably close to the directly obtained value .0080 for the mean inbreeding coefficient for all sibs in generations 5 through 8.

DISCUSSION

In previously published estimates of inbreeding coefficients in human populations, samples of matings have been classified into inbred *versus* outbred and a coefficient of inbreeding estimated from the ratio of first cousin, second cousin, and other consanguineous matings (usually not beyond third cousins once removed) to "unrelated" matings. The size of the sibship produced by the two sorts of mating is not entered into such estimates. We have 123 cases of 61 different sorts of inbred matings out of a total of 316 matings (including the sixty-second sort, "unrelated") for generations 5 through 8. i_0 for inbred matings is $(1.9847/123) = .0161$ and for total matings i_0 is $(1.9847/316) = .0063$. This estimate is lower than the estimate we obtained for total individuals in generations 5-8 ($i_0 = .0080$) because our inbred families of generations 5-8 have more offspring than the outbred families.[1]

Caution is required for the proper interpretation of our population mean coefficient of inbreeding. First, the value should be regarded as a minimum estimate of the true value of the coefficient. As a result of extensive field work over a period of 16 years, the Ramah genealogies are remarkably complete for generations 2-8. There are some unknowns in the founding generation. If any of the 14 founders are themselves *inbred*, the mean values of the population coefficient would be slightly larger. However, since no inbreeding was practiced in generations 2-4 (where genealogical information is "complete") this possible source of error would not greatly modify the total population estimates (on the assumption, of course, that there are no undetected relationships among the founders).

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[1] The crude data suggest that inbreeding in the Ramah population has not reduced fertility of inbred individuals, although when the data for all generations are pooled the average size of outbred sibships is 3.53 persons, and for inbred sibships, 3.44 persons. However, when the crude data are compared by generation, inbred sibships average consistently larger than outbred, the respective means for generations 5-8 being 3.44 as against 3.20. The larger sibships in the earlier generations (mean of generations 2-4 = 4.45) make a relatively large contribution to the population mean. Of course such crude data may be highly misleading. Many of the families of generation 7 and 8 are incomplete. In a later paper on the demography of the Ramah group we will examine the size of inbred and outbred sibships in terms of exposure to pregnancy. For the present we may conclude that inbreeding in the present group has not been accompanied by a marked decrease in fertility.

If there are undetected *biological relationships among* the 14 founders, the mean values for subsequent generations could be increased considerably. However, the known relationships among the founders is of the sort which might be expected on the basis of general knowledge of Navaho behavior. With due regard to the unknowns in the case, our opinion is that the estimated values for the population, while somewhat low, are not greatly low, perhaps not more than 10%.

Another difficulty in arriving at an estimate of the true value of the inbreeding coefficient is the problem of determining true population size. Although the Ramah group is relatively isolated (see above) and relatively self-contained, there are a few individuals regarding whose membership in the population an arbitrary judgment must be made. Actually we made an independent classification of the individuals represented in the census data of the Ramah area. These data include information of residential history, travel, participation in other Navaho communities, and work in extra-Navaho contexts. The census included information on a number of individuals who have a marginal participation (in both biological and socio-cultural terms) in the Ramah population. Our result differed only with regard to a single outbred family with 9 children. JNS classed the entire family in the population while CK put the father in, and the remainder of the family out of the population. For the present calculations, all 11 individuals have been included in the population. If our criteria for membership were made extremely broad, the population size, as of September first 1948, would be increased by some 20 individuals, and the size over all generations reported here would be larger by about 70 individuals. Use of the larger population sizes would result in a slight reduction of the population estimates of the mean value of the inbreeding coefficients, but not a marked reduction because some of these 70 individuals are themselves inbred.

In previously published estimates, data have not been available on the more remote relationships. It is of interest to compare our results based on "full" specification with those obtained when the coefficient is estimated from various degrees of incomplete specification. We will examine three cases: 1) estimates from the incidence of first cousin (1C) matings; 2) estimates based on the incidence of first and second cousin (1C + 2C) matings; and 3) estimates based (as in the Hiroshima and Kure data reported in Neel, et al., '49) on the incidence of matings involving first cousins, first cousins once removed, second cousins, second cousins once removed, third cousins, and third cousins once removed.

Case	Based on Relationships	Estimate of i_0	Percentage of total $i_0 = (.0080)$ contributed by these matings
1.	F1C	.0008	10.0
2.	F1C+F2C	.0020	25.0
3.	F1C+F1C1R+F2C1R+F3C+F3C1R	.0034	42.5

In the case of the Ramah population, our estimate for the generations reported here would have neglected about 57% of the known inbreeding had we restricted our study 1) to degrees of relationship equal to or greater than third cousins, and 2) to specification of a single (closest) type of relationship for each inbred mating.

This datum is not of direct use in estimating the amount of underestimation of the inbreeding coefficient in other studies. The datum is closely influenced by factors specific for the Ramah community, for example, the effective size of the local breeding population, and the local Navaho cultural patterns of mate selection. However, the datum is suggestive for the interpretation of reported values for the inbreeding coefficient. We might guess, for instance, that the estimate by Neel et al. ('49) and by Schull ('53) in the Japanese case—where marriages of first cousins are culturally permissive and actually performed fairly often—would be closer to the true value, than the estimate of Haldane and Moshinsky ('39) based on data of Orel ('32) in the case of Catholic marriages in the archdiocese of Vienna where marriage of first cousins is by special dispensation and not a culturally preferred type of mating. In these studies, the specification of relationships was restricted to degrees equal to or greater than third cousins and multiple relationships were not specified.

SUMMARY

Inbreeding coefficients are calculated for 316 matings which produced 1118 offspring during 7 generations of the Ramah population. Of the 316 sibships, 123 are inbred. The range of the inbreeding coefficient for individuals is .0010-.0977, the mean for inbred siblings is .0175, and the mean for the later generations 4 through 8 is .0080, and the mean for the total population, generations 1 through 8, is .0066. These values are minimum estimates for the population.

Coefficients of the order observed for the Ramah Navaho, while about two times those found for Japan and 4 times those reported for Europe, are small compared to the estimate for the Dunker isolates in the United

States and compared to such regular systems of inbreeding as full first cousin mating.

Although the small Ramah Navaho population is not highly inbred, mating of the more remote relatives makes a comparatively large contribution to the mean value of the inbreeding coefficient.

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STUDIES ON THE VARIABILITY OF HUMAN URINARY EXCRETION PATTERNS

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INTRODUCTION

As our knowledge of biochemical genetics increases, the question of the genetic control of human differences comes more to the forefront. Some of the "inborn errors of metabolism," such as alcaptonuria and phenylketonuria, have been recognized for many years. More recently attention has been focused on the differences which occur between people whose various metabolic processes fall within the normal range of variation. While some of these differences are undoubtedly a function of the environment of the individuals, evidence is accumulating which indicates that many of the observed differences are of a more fundamental nature and that some of them may have their origin in genetic differences between the individuals.

Many experiments, although not designed to demonstrate these genetic relationships, show the marked individuality which exists for many body constituents. McGavack and Drekter ('45) found that thyrotoxic patients show changes in blood cholesterol after treatment with thiouracil, but each person maintained his relative position with respect to the other patients. Groen and coworkers ('52) subjected 60 individuals to diets containing from one to 900 mg cholesterol/day and were able to change the blood levels only slightly. They found that each person reacted in his own characteristic way to the different diets. They suggested that the cause of these individual peculiarities may be of a hereditary nature.

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Serum alkaline phosphatase in cattle has been shown to vary widely among individuals although remaining relatively constant for a particular animal (Crookshank, et al., '52); Wagner and Poindexter ('52) reported a constitutional individuality in the level of cholesterol-esterifying activity in human serum. Kajiro and coworkers ('52) have reported on a constitutional anomaly in which there is a lack of the enzyme catalase in the blood and certain tissues. Wilkins and Carlson ('52), studying the qualitative differences in neutral 17-ketosteroids excretion in normal subjects, found that although the total amounts excreted in the urine might vary with environmental changes, the qualitative pattern of each person was highly characteristic for the individual.

Among the more interesting recent studies in biochemical genetics have been the demonstrations that genetically controlled variations in human hemoglobin exist. Itano ('53) has summarized some of the properties of the different hemoglobins along with their relationships to certain blood conditions.

Of the various anomalies of amino acid excretion, cystinuria has perhaps been most adequately studied. Dent and Harris ('51) have summarized the characteristics of the different types of cystinuria, emphasizing the genetic relationships. The increased excretion by some people of the recently discovered amino acid β-aminoisobutyric acid is reported to have a genetic basis (Crumpler, et al., '51). Fink, Henderson, and Fink ('51) also found the excretion of this amino acid to vary widely from person to person. With the advent of paper chromatography, a number of studies of individuality in urinary excretion patterns have been made (e. g. Williams, '51; Berry, Cain, and Rogers, '51; Sutton, '51). An interpretation of these results in terms of the genetic makeup of the individual has recently been made (Berry, '53).

The results reported here are from a study of urinary excretion products of 32 individuals (16 sib pairs). The data were analyzed in such a way as to answer the following questions: (1) Does an individual on repeated sampling tend to show a characteristic level of excretion of the particular substances measured? (2) If so, does the individual tend to resemble his sibling in this respect more than would be expected by chance? (3) Can individuals be characterized by excretion *patterns* as opposed to excretions of particular substances? The affirmative answers which have been obtained should help form a sound basis for further study in the field of human biochemical genetics.

EXPERIMENTAL

The subjects of this study were 32 patients of the Coldwater State Home and Training School, Coldwater, Michigan, and consisted of 16 pairs of siblings. Two of the sib pairs, on the basis of their serological and morphological types, were probably identical twins (kindreds 08 and 13). All of the patients were classified as mentally deficient with no known organic defect. Both members of kindred 29 were blind or nearly blind, however. There were 13 males and 19 females whose ages varied from 7 to 33 and whose IQ's varied from 28 to 83. The sexes are indicated in table 1.

Three first morning urine samples were collected from each of the patients on alternate days. All samples were collected within a three-week period. The samples were frozen soon after collection and were stored in that state except when necessary to remove aliquots for analysis.

Creatinine determinations were done by the method of Bonsnes and Taussky ('45) and inorganic phosphorus by the method of Fiske and SubbaRow ('25). All other substances were measured by paper chromatographic techniques using conditions previously specified (Sutton, '51) except that aliquots of urine containing 40 μg creatinine were used for the bromcresol green (BCG) chromatograms. One alteration in the procedure was the use of reflectance measurements to quantify those amino acids for which ninhydrin had been used for color development. For this purpose a Beckman model B spectrophotometer equipped with an integrating sphere reflectance attachment with beam expanding lens was used. The filter paper containing the ninhydrin-developed amino acid was placed in the instrument so that the light beam (550 mμ) was centered on the point of maximum color density. Quantitative values for the unknowns were obtained by comparing their percentage reflectance with a standard curve based on the reflectances of known quantities treated in the same manner. Alanine was used as the standard for glutamine, ethanolamine and β-aminoisobutyric acid, and the values for these substances are expressed as mg alanine. This procedure requires considerably less time than most other methods in the literature and is capable of the same accuracy.

The substances designated "BCG acid .28," "BCG acid .30," and "BCG basic .32" refer to spots of unknown composition which appear on bromcresol green chromatograms resolved in butanol-acetic acid-water

TABLE 1

Measurements of Urinary Constituents

Subject		Sex	Age		IQ	pH			Spec. Grav. (−1, x10³)			Optical Dens. (x 10³)			Creatinine (Cr) mg/ml			Phosphorus mg P/ml		
			yr	mo		A*	B	C	A	B	C	A	B	C	A	B	C	A	B	C
22	33	F	26	1	63	6.25	5.52	6.25	31	25	12	048	052	101	1.70	1.70	0.78	1.49	1.22	0.42
22	34	F	24	2	61	5.58	5.49	5.77	19	23	27	073	367	052	1.54	2.12	2.68	1.12	1.68	1.65
14	25	M	11	5	60	6.49	6.21	6.18	15	10	16	312	213	217	0.80	0.70	0.59	0.60	0.40	0.73
14	24	M	12	9	59	7.36	6.23	6.98	16	19	10	177	258	485	0.64	0.65	0.40	0.48	0.70	0.43
23	35	M	27	3	39	5.78	5.74	5.72	18	24	22	066	035	043	1.22	1.82	1.52	0.72	1.60	1.07
23	36	M	17	8	54	6.02	5.43	6.43	18	26	22	053	051	077	1.00	2.13	1.25	0.58	1.66	0.76
24	37	M	7	6	58	6.11	5.92	6.17	20	26	04	103	204	088	0.66	1.04	0.28	0.93	1.08	0.26
24	38	F	14	11	58	5.54	5.56	5.73	15	21	18	032	056	067	1.35	1.68	1.07	0.91	1.11	0.84
25	39	M	22	2	53	5.46	5.76	5.86	29	32	23	102	097	034	1.98	3.47	2.08	1.91	2.37	1.46
25	40	M	16	8	61	6.41	6.06	5.68	27	29	30	332	122	077	1.75	1.96	1.48	0.95	1.28	1.42
12	21	F	31	6	53	5.66	6.82	5.43	18	17	15	091	302	117	1.56	0.99	0.90	0.70	0.69	0.66
12	20	F	25	3	39	7.12	6.42	6.69	21	18	21	193	123	152	1.68	1.19	1.32	1.17	1.16	0.87
26	41	M	14	9	28	6.15	5.58	5.98	15	28	27	082	038	170	0.64	1.62	0.95	0.52	0.77	0.85
26	42	M	13	4	28	6.08	5.86	5.83	23	17	22	340	276	156	0.80	0.85	0.90	0.73	0.58	0.75
09	15	M	17	8	62	7.48	6.07	6.63	05	18	19	048	027	034	0.55	1.59	1.30	0.10	0.84	0.55
09	14	M	12	6	83	6.86	6.93	6.43	12	10	19	038	054	145	0.61	0.72	0.83	0.25	0.23	0.71
27	43	F	10	0	69	5.42	5.05	5.74	15	29	29	044	047	083	0.58	1.04	1.29	0.57	0.85	1.77
27	44	F	12	1	59	7.30	7.44	6.58	14	22	18	136	156	125	0.67	0.66	0.79	0.31	0.50	0.74
11	19	F	21	4	48	6.53	6.36	6.13	15	19	27	146	202	121	0.93	1.23	1.83	0.61	0.97	1.55
11	18	M	18	6	64	5.70	6.53	5.63	26	25	26	138	076	112	1.82	1.78	1.68	1.65	1.54	1.29
07	11	F	11	9	54	6.32	6.49	5.83	25	33	31	344	072	142	1.28	1.67	1.53	1.10	1.71	2.33
07	10	F	18	5	64	6.04	6.02	5.94	28	30	30	092	102	106	1.50	1.90	2.69	1.61	1.92	2.18
28	45	M	7	4	56	5.93	6.43	6.22	24	18	26	057	113	114	1.08	0.79	1.27	0.65	0.58	1.11
28	46	F	13	5	61	6.58	6.22	6.56	23	25	23	065	143	102	1.15	1.93	1.24	0.77	1.08	0.72
29	47	F	12	11	63	5.72	8.82	6.76	28	23	25	042	093	075	1.99	1.20	1.19	1.55	0.65	0.88
29	48	F	11	1	63	7.17	7.05	6.42	21	20	23	112	087	052	0.90	0.90	1.14	0.55	0.63	1.06
08	13	F	7	5	76	7.12	6.18	6.26	11	28	20	315	162	056	0.53	0.52	0.96	0.66	0.80	0.80
08	12	F	7	5	76	7.43	6.22	6.07	17	05	18	067	081	097	0.42	0.73	0.84	0.17	0.73	0.98
13	22	F	10	6	59	5.91	7.78	6.12	16	11	15	288	590	232	0.59	0.45	0.70	0.43	0.33	0.73
13	23	F	10	6	71	8.23	6.32	6.43	16	17	21	301	287	258	0.78	0.50	0.76	0.63	0.65	0.94
10	16	F	33	2	68	5.73	6.22	5.92	12	07	08	042	078	091	1.23	0.44	0.44	1.06	0.35	0.27
10	17	F	27	9	75	6.18	7.53	5.53	18	14	15	049	033	046	1.19	1.12	1.35	0.87	0.78	0.85

* A, B and C refer to the three samples for each individual.

TABLE 1 (Continued)

Subject		Uric acid mg/ml			Histidine·HCl mg/ml			Alanine μg/mg Cr			β-Aminoiso-butyric acid μg/mg Cr			Glutamic acid μg/mg Cr			Glutamine μg/mg Cr			Ethanolamine μg/mg Cr		
		A	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
22	33	0.35	0.15	0.12	0.12	0.12	0.05	17	07	06	06	00	00	02	02	02	17	11	09	00	00	00
22	34	0.20	0.30	0.12	0.12	0.10	0.12	11	11	11	00	00	00	00	00	00	13	13	13	00	00	00
14	25	0.20	0.35	0.30	0.02	0.05	0.10	27	09	19	15	NV	15	08	00	00	32	15	24	06	00	06
14	24	0.20	0.05	0.20	0.10	0.10	0.05	20	18	15	11	15	NV	10	00	05	29	25	21	00	08	00
23	35	0.20	0.30	0.25	0.10	0.12	0.10	06	11	10	00	06	00	00	00	00	12	16	11	02	04	00
23	36	0.25	0.40	0.70	0.10	0.10	0.12	12	11	15	00	00	00	00	00	00	12	11	16	00	00	00
24	37	0.20	0.50	0.03	0.12	0.17	0.01	45	61	30	05	NV	00	00	00	05	48	57	23	11	16	06
24	38	0.15	0.40	0.20	0.12	0.12	0.10	11	11	19	00	03	06	00	00	00	13	13	25	00	02	05
25	39	0.30	0.50	0.25	0.12	0.12	0.10	14	11	13	00	00	00	00	00	00	14	13	16	04	00	00
25	40	0.15	0.40	0.40	0.12	0.15	0.15	36	18	20	00	00	00	NV	NV	00	40	25	23	00	00	02
12	21	0.40	0.25	0.30	0.12	0.12	0.10	19	25	27	07	08	NV	00	00	00	21	18	32	00	06	06
12	20	0.60	0.40	0.50	0.12	0.12	0.15	11	18	23	08	08	NV	10	02	00	19	27	32	00	06	06
26	41	0.25	0.40	0.15	0.15	0.15	0.20	38	27	68	04	00	10	00	00	00	38	24	68	03	00	08
26	42	0.25	0.25	0.08	0.15	0.15	0.15	57	29	38	00	06	00	00	00	00	43	24	32	02	02	02
09	15	0.07	0.12	0.25	0.10	0.12	0.12	19	19	17	19	13	15	11	07	08	19	14	21	00	00	00
09	14	0.20	0.25	0.22	0.10	0.06	0.10	32	15	20	14	12	13	00	05	07	29	18	40	05	00	06
27	43	0.15	0.15	0.50	0.08	0.10	0.15	17	27	17	04	NV	05	00	00	00	21	32	29	03	04	03
27	44	0.15	0.25	0.40	0.10	0.15	0.10	30	38	29	06	10	04	07	10	06	40	51	36	04	00	00
11	19	0.25	0.80	0.60	0.12	0.15	0.15	25	24	21	10	NV	06	05	02	01	32	34	27	06	05	04
11	18	0.50	0.55	0.50	0.12	0.12	0.12	13	13	13	00	13	10	00	05	00	19	20	24	04	06	06
07	11	0.80	1.10	0.60	0.17	0.40	0.40	36	68	34	07	NV	03	00	05	00	48	86	68	04	04	00
07	10	0.80	0.60	1.20	0.15	0.15	0.12	20	32	13	07	NV	02	05	02	02	29	38	19	00	00	00
28	45	0.35	0.15	0.30	0.15	0.10	0.20	40	25	48	00	00	13	00	05	NV	54	45	64	09	04	09
28	46	0.15	0.30	0.15	0.20	0.15	0.15	43	17	24	08	00	08	00	00	00	57	25	38	09	02	02
29	47	0.40	0.20	0.10	0.15	0.15	0.15	23	36	24	00	05	00	00	09	NV	24	30	30	00	00	00
29	48	0.20	0.20	0.20	0.10	0.10	0.15	34	23	29	11	06	10	NV	05	06	36	23	29	00	00	00
08	13	0.50	0.18	0.35	0.05	0.10	0.08	13	30	14	08	17	07	08	05	04	13	32	20	00	09	00
08	12	0.10	0.12	0.25	0.02	0.10	0.08	09	19	11	05	NV	07	04	00	04	12	21	21	00	06	04
13	22	0.15	0.03	0.20	0.04	0.05	0.06	24	27	19	11	11	09	00	11	00	29	32	36	08	00	09
13	23	0.10	0.15	0.20	0.10	0.10	0.10	24	40	24	NV	NV	10	11	00	00	10	40	36	NV	08	09
10	16	0.25	0.04	0.10	0.08	0.03	0.04	14	09	20	00	02	03	02	02	05	11	11	18	00	00	00
10	17	0.15	0.07	0.05	0.12	0.10	0.10	12	10	10	03	00	00	06	03	02	12	10	13	00	00	00

NV = No Value.

TABLE 1 (Continued)

Subject		Glycine μg/mg Cr			Lysine μg/mg Cr			Taurine μg/mg Cr			Threonine μg/mg Cr			BCG acid .28 area (in²)			BCG acid .30 area (in²)		
		A	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
22	33	22	10	14	16	07	05	14	10	20	11	00	00	.30	.17	.00	.00	.16	.00
22	34	27	18	24	05	05	10	04	00	00	10	00	13	.28	.21	.23	.00	.00	.00
14	25	18	08	08	33	14	18	23	32	21	23	14	15	.00	.00	.00	.00	.00	.00
14	24	13	08	08	44	23	30	16	14	20	19	19	13	.00	.00	.00	.00	.00	.00
23	35	14	20	12	12	14	10	14	20	23	11	15	00	.11	.12	.24	.00	.12	.11
23	36	12	09	20	10	07	10	10	27	14	10	00	13	.00	.29	.16	.00	.10	.00
24	37	67	110	63	48	89	18	30	80	400	23	NV	15	.00	.18	.16	.00	.00	.11
24	38	24	22	38	14	12	40	10	07	07	11	00	19	.18	.14	.19	.09	.12	.00
25	39	40	30	22	07	00	07	23	20	25	14	10	11	.20	.25	.13	.00	.00	.00
25	40	45	27	23	33	14	07	17	17	21	21	14	15	.12	.08	.20	.00	.00	.09
12	21	17	24	23	16	20	20	27	17	16	15	22	23	.17	.16	.13	.00	.00	.22
12	20	22	24	29	00	16	14	00	23	16	13	21	21	.20	.14	.18	.00	.00	.00
26	41	34	24	63	30	14	51	28	19	28	23	14	38	.13	.25	.22	.12	.08	.00
26	42	23	20	20	26	23	20	19	32	38	21	18	19	.10	.12	.23	.00	.00	.00
09	15	26	34	19	00	33	00	07	17	05	15	23	14	.16	.15	.24	.00	.00	.00
09	14	45	36	32	23	10	18	25	23	16	27	18	33	.11	.09	.14	.00	.00	.00
27	43	29	17	22	18	16	18	16	02	20	15	15	18	.32	.53	.52	.00	.22	.25
27	44	45	48	54	23	00	23	20	20	40	19	25	31	.00	.00	.00	.00	.00	.00
11	19	26	29	23	55	92	33	07	16	10	21	21	16	.20	.24	.24	.00	.00	.00
11	18	10	18	14	12	20	23	32	14	35	00	18	15	.21	.09	.14	.15	.00	.07
07	11	40	57	40	59	96	33	21	27	32	35	46	41	.12	.13	.42	.00	.00	.31
07	10	24	27	20	16	20	10	NV	25	25	25	19	14	.26	.25	.30	.00	.00	.00
28	45	48	38	71	55	59	63	60	32	40	23	18	22	.38	.12	.40	.15	.13	.00
28	46	89	38	57	55	14	20	23	19	19	33	19	25	.43	.18	.14	.00	.15	.00
29	47	30	36	27	10	16	12	32	25	10	19	19	22	.18	.19	.06	.00	.00	.00
29	48	51	34	54	18	12	12	02	14	05	25	15	14	.00	.00	.25	.00	.00	.00
08	13	08	16	13	00	44	12	05	53	17	13	27	15	.00	.26	.20	.00	.16	.00
08	12	06	15	17	10	23	16	00	19	49	11	19	21	.00	.17	.21	.00	.00	.00
13	22	12	24	17	14	00	18	05	00	00	19	23	22	.00	.00	.00	.00	.00	.00
13	23	28	20	13	NV	26	18	NV	17	10	NV	27	19	.09	.00	.00	.00	.00	.00
10	16	26	16	26	10	00	14	12	14	12	15	11	19	.14	.00	.00	.25	.00	.00
10	17	34	20	17	00	05	00	12	16	14	14	16	21	.16	.00	.18	.00	.28	.23

NV = No Value.

TABLE 1 (Continued)

Subject		BCG basic .32 area (in²)			"Hippuric acid" area (in²)			"Lactic acid" area (in²)			DSA purple .90 area (in²)			DSA orange .85 area (in²)		
		A	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
22	33	.52	.00	.53	.09	.22	.24	.00	.06	.27	.16	.13	.10	.18	.35	1.03
22	34	.22	.21	.26	.33	.32	.07	.11	.00	.00	NV	NV	.13	.58	.69	.28
14	25	.58	.37	.24	.22	.24	.37	.13	.19	.52	.34	.28	.42	.30	.00*	.16
14	24	.53	.20	.60	.61	.31	.12	.00	.22	.00	.27	.32	.34	.15	.40	.00
23	35	.00	.00	.00	.12	.22	.18	.00	.00	.07	.10	.35	.26	.27	.75	.65
23	36	.42	.00	.33	.29	.19	.18	.24	.00	.17	.17	.20	.29	.58	.63	.53
24	37	.50	.00	.00	.20	.29	.04	.48	.32	.07	.27	.26	.08	.29	.18	.00
24	38	.00	.00	.26	.00	.00	.02	.00	.00	.03	.12	.10	.29	.00	.14	.15
25	39	.00	.00	.36	.16	.21	.15	.00	.00	.00	.24	.27	.27	.40	.00	.00
25	40	.52	.41	.00	.08	.07	.29	.03	.09	.00	.25	.14	.23	.09	.25	.42
12	21	.29	.34	.00	.23	.44	.62	.16	.18	.17	.27	NV	NV	.28	.37	.41
12	20	.80	.20	.32	.30	.24	.34	.12	.00	.08	NV	.54	.24	.12	.17	.57
26	41	.00	.00	.33	.24	.32	.42	.54	.37	.65	.18	.19	.29	.16	.08	.48
26	42	.20	.16	.00	.34	.28	.41	.58	.53	.72	.30	.29	.30	.15	.00	.59
09	15	.60	.13	.49	.32	.10	.19	.29	.13	.23	.45	.35	.38	.48	.28	.32
09	14	.26	.25	.27	.21	.04	.29	.29	.00	.45	.24	.09	.25	.40	.37	.62
27	43	.00	.00	.00	.22	.20	.28	.35	.39	.53	.27	.30	.31	.53	.72	.46
27	44	.45	.81	.76	.18	.18	.15	.17	.57	.57	.22	.28	.32	.43	.44	.53
11	19	.31	.13	.28	.35	.29	.21	.00	.00	.23	.18	.16	.22	.21	.29	.20
11	18	.00	.40	.00	.00	.34	.22	.00	.00	.14	.21	.21	.24	.27	.36	.29
07	11	.20	.35	.00	.04	.27	.27	.52	.20	.36	.17	.20	.24	.00	.00	.00
07	10	.11	.19	.00	.19	.24	.16	.33	.39	.51	.18	.11	.08	.00	.00	.00
28	45	.00	.00	.00	.18	.29	.24	.21	.47	.58	.59	.77	.61	.50	.82	.57
28	46	.00	.00	.00	.20	.25	.25	.20	.11	.00	.30	.37	.32	.41	.15	.24
29	47	.00	.41	.52	.08	.09	.16	.27	.05	.08	.15	.17	.17	.20	.00	.00
29	48	.71	.73	.54	.07	.20	.10	.32	.34	.12	.09	.12	.10	.00	.00	.31
08	13	1.07	.00	.00	.13	.51	.34	.29	.40	.27	.22	.57	.27	.00	.26	.54
08	12	.83	.00	.00	.04	.31	.26	.19	.40	.46	.14	.47	.22	.00	.48	.27
13	22	.17	.57	.31	.39	.00	.25	.40	.10	.40	.23	.15	.27	.46	.18	.00
13	23	.49	.30	.13	.10	.39	.27	.00	.55	.64	NV	.39	.35	.00	.25	.21
10	16	.00	.43	.32	.20	.17	.57	.11	.00	.54	.23	.30	.34	.27	.00	1.14
10	17	.12	.00	.00	.46	.42	.35	.17	.05	.14	.29	.40	.29	.80	.64	.41

* In some instances where the value .00 appears, the substance was actually present but in quantities too small to form a discrete area.

NV = No Value.

(80 : 20 : 20) solvent.[2] The numerals indicate the Rf values at which these spots appear. "Hippuric acid" and "Lactic acid" refer to acid spots appearing on bromcresol green chromatograms at the expected position for the indicated acids. It is possible that other acids contribute to these spots, however. The substances designated "DSA orange .85" and "DSA purple .90" appear on chromatograms which have been sprayed with diazotized sulfanilic acid. The spots occuring on the bromcresol green and the diazotized sulfanilic acid (DSA) chromatograms have been quantified by carefully marking the area of the spots with a pencil and then measuring the area with a polar planimeter. In studies of the DSA spots, it has been found that over the range likely to be found in urine the area of the spot is approximately linearly related to the amount of material present. Occasionally the presence of salicylate metabolites prevented an accurate quantitative estimation of some of the substances detected chromatographically. In such cases, "no value (NV)" was recorded.

The optical density measurements were made by comparing the undiluted sediment-free samples with water in a spectrophotometer at 620 mμ.

RESULTS

The original measurements of the urinary constituents are presented in table 1. The mean and standard deviation for each item are shown in table 2. In most cases, the measurements have been expressed as creatinine ratios in table 2, since this ratio is a more significant quantity. For most of these items, no population norms have been established; however, no grossly abnormal samples were encountered and these measurements are comparable to those reported in other studies (Berry, '53; Beerstecher, et al., '50; Young, et al., '51). The lack of a comparable control group makes it impossible to detect any minor peculiarities which may be associated with this experimental group. Studies on this group will, however, give information on individual consistency and sibship similarities.

To test the reliability of the measurements as a function of individual differences, an analysis of variance was carried out considering the sample as composed of 32 individuals with three measures each. The F values

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[2] The somewhat varying Rf values for these substances has resulted in different designations by different authors. Berry ('53) designates as "BCG acid .30" what is here called "BCG acid .28." She does not report on the spot here called "BCG acid .30."

TABLE 2

Analysis of variance for individual and intrasibship consistency of urinary excretion products

No.	Substance	Mean	σ	Individual Consistency			Intrasibship Consistency		
				F	d.f.	p	F	d.f.	p
1	DSA orange .85 (in^2)	.303	.251	2.282	64, 31	.005	9.691	16, 15	.001
2	Creatinine (mg/ml)	1.19	.63	5.317	64, 31	.001	4.045	16, 15	.01
3	BCG acid .28 (in^2)	.152	.121	3.545	64, 31	.01	1.409	16, 15	$>.1$
4	BCG acid .30 (in^2)	.038	.075	1.293	64, 31	$>.1$	1.102	16, 15	$>.1$
5	"Hippuric acid" (in^2)	.231	.131	1.645	64, 31	.05	4.109	16, 15	.01
6	Taurine (μg/mg Cr)*	23.3	41.1	1.771	60, 29	.05	0.768	14, 13	$>.1$
7	BCG basic .32 (in^2)	.233	.239	2.339	64, 31	.005	1.222	16, 15	$>.1$
8	Histidine·HCl (μg/ml)	118	56	5.426	64, 31	.001	2.430	16, 15	.05
9	Phosphorus (mg/mg Cr)	.797	.248	2.395	64, 31	.005	2.496	16, 15	.05
10	Optical density (x 1000/Cr)	15.7	20.7	3.828	64, 31	.001	4.906	16, 15	.005
11	Glutamic acid (μg/mg Cr)	2.48	3.34	2.129	56, 27	.01	1.797	13, 12	$>.1$
12	Lysine (μg/mg Cr)	21.1	19.9	4.024	62, 30	.001	1.602	15, 14	$>.1$
13	DSA purple .90 (in^2)	.264	.123	5.918	56, 27	.001	1.694	13, 12	$>.1$
14	"Lactic acid" (in^2)	.225	.203	3.774	64, 31	.001	4.948	16, 15	.005
15	Glycine (μg/mg Cr)	28.5	17.9	7.711	64, 31	.001	2.384	16, 15	.1
16	Specific gravity (–1, x10^3, /Cr)	18.9	7.1	2.577	64, 31	.005	3.680	16, 15	.01
17	Uric acid (mg/mg Cr)	.269	.163	3.407	64, 31	.001	3.083	16, 15	.05
18	pH	6.27	.64	2.077	64, 31	.01	1.781	16, 15	$>.1$
19	Ethanolamine (μg/mg Cr)	2.67	3.36	2.711	62, 30	.001	1.833	15, 14	$>.1$
20	β-Aminoisobutyric acid (μg/mg Cr)	5.48	5.25	5.124	42, 20	.001	10.445	11, 10	.001
21	Alanine (μg/mg Cr)	22.8	12.9	4.554	64, 31	.001	2.356	16, 15	.1
22	Glutamine (μg/mg Cr)	27.1	15.0	5.869	64, 31	.001	3.667	16, 15	.01
23	Threonine (μg/mg Cr)	17.8	8.47	4.365	60, 29	.001	2.663	14, 13	.05

* Cr = Creatinine.

are shown in table 2 with their levels of significance indicated. The high level of significance obtained for nearly every item certainly justifies the conclusion that even items falling within the middle of the normal range occur at levels characteristic of the particular individual.

A further hypothesis—whether or not siblings tend to resemble each other more than could be expected by chance—was tested by considering the sample to be made up of 16 groups of two individuals each. For this purpose the averages of the three measures were used as the value for that individual. These results are also shown in table 2. The larger number of substances failing to show significance may in part be due to the fact that higher F values are necessary to attain a given level of significance when the sample is reduced in size as it is in the intersibship comparison. Further work with a larger number of subjects will be necessary before conclusions can be drawn regarding the intrasibship similarity.

The origin of the intrasibship similarities would seem most probably to lie in their similar genetic makeup. The diet, which is the environmental variant most likely to influence the composition of the blood and urine, was fairly constant for all subjects because of their institutional status. Other studies (Thompson and Kirby, '49; Sutton, '51; Groen, et al., '52) have shown diet to be relatively unimportant in determining the levels of many body metabolites. The relative importance of heredity versus diet remains a subject for further study, however. Experiments are in progress in this laboratory which should throw additional light on this matter.

In order to have a quantitative measure of the degree of intrasibship concordance, the indices shown in table 3 have been calculated. The similarity index is the reciprocal of the mean square average difference in standard scores between siblings for all the items measured. The column headed "r_{12}" is the product moment correlation based on the 12 items of table 2 which showed an intrasibship similiarity significant at least at the 5% level. The column headed "r_{23}" is the correlation coefficient based on all 23 items of table 2. Inspection of the table reveals a fairly close agreement between the two correlations and the index of similarity. Part of the difference is undoubtedly due to the fact that the correlation coefficient places emphasis on congruence of the extreme values while the index of similarity places equal emphasis on congruence of intermediate and extreme values. A choice between these indices is difficult until more is known concerning the relative importance to heredity of absolute levels versus related *patterns* of excretion. It is interesting to note that neither of the two sets of twins (sibships 08 and 13) ranks highest in similarity as calculated in table 3.

One interesting form in which individual variations occur is in the different *patterns* of urinary excretion. By this is meant the relative amount of each substance present when compared with other substances.

TABLE 3

Comparisons of profile similarities within sibships

Sibship	Sex	Index of Similarity	r_{12}	r_{23}
23	♂♂	11.6	.437	.350
22	♀♀	10.6	.563	.463
26	♂♂	9.8	.407	.339
10	♀♀	8.9	.432	.374
14	♂♂	8.4	.699	.538
13	♀♀	8.1	.625	.501
12	♀♀	7.8	.132	.042
29	♀♀	7.4	−.003	.206
25	♂♂	6.9	.301	.201
11	♂♀	6.8	.099	.058
09	♂♂	6.8	.396	.236
08	♀♀	6.3	.229	.169
28	♂♀	5.1	.175	.448
07	♀♀	3.7	.634	.323
27	♀♀	3.3	.180	−.308
24	♂♀	3.1	−.094	−.084

Figure 1 shows such individual patterns or profiles. The values plotted are the standard scores, obtained for each item by subtracting the group mean from the individual value and then dividing by the standard deviation. The results thus expressed are comparable from one substance to another. Sibships 22 and 23, whose profiles are shown in figure 1, possess a pattern observable to some extent in at least 10 of the 32 individuals studied. These similarities were first observed on graphs in which the items were plotted in a random sequence. In order to make the similarity more obvious, the individual items of the 4 subjects whose patterns were most nearly consistent with each other (sibships 22 and 23) were ranked in order of decreasing size for each subject. The average rank of each item was then obtained, and the sequence of items shown in figure 1 is in terms of these increasing average ranks.

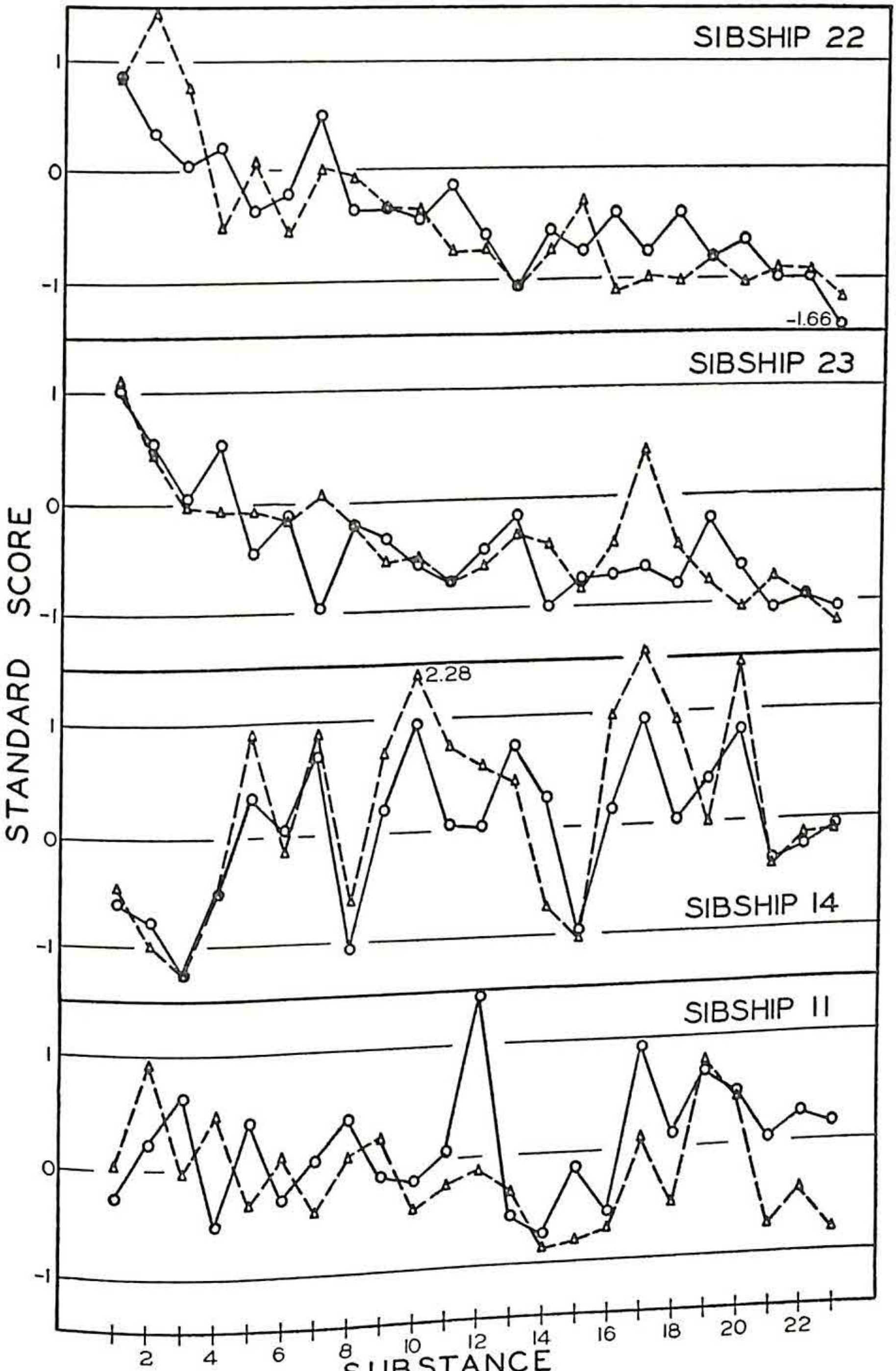

FIG. 1. PROFILES OF URINARY EXCRETION PATTERNS OF FOUR PAIRS OF SIBLINGS. THE SUBSTANCES ARE NUMBERED AS IN TABLE 2.

The resemblance between the profiles of sibships 22 and 23 is striking. By contrast, the profiles of sibship 14 seem to show a completely unrelated pattern, although the concordance within this sibship is high. The profiles of sibship 11 resemble those of sibships 22 and 23 for many of the items. The concordance of the siblings for the marked deviations which occur indicates that this deviation is not a matter of chance. At least three different patterns of excretion of the type discussed here have been found which were common to two or more sibships in this study.

DISCUSSION

Of particular interest in the past have been such anomalies of urinary excretion as alcaptonuria and cystinuria, conditions which are characterized by excretion of one or a few substances at levels many times higher than are usually found in a normal population. There probably are many such genetically controlled conditions whose presence goes unnoticed because the principal point of interference with metabolic processes lies too far removed from the easily measurable materials such as blood and urine. Many differences must also exist whose effect at any point in the metabolic processes is small.

By the use of such an approach as is presented here, it is hoped that some inroad can be made into the area of the integral differences between individuals. The detection of differences in *patterns* of excretion should provide a new means of classifying human beings, perhaps into discrete groups, which will make family studies more fruitful. The primary variables which are responsible for these profile differences are as yet not well understood. A statistical approach such as multiple factor analysis should furnish considerably more insight in this area.

SUMMARY

The urinary excretion products of 16 sib-pairs who are mentally deficient were analyzed chemically for creatinine, phosphorus, amino acids, and other substances which can be detected on paper chromatograms. Analysis of variance showed that most of the substances are excreted at levels characteristic of the individual and that siblings tend to resemble each other more than do unrelated persons. Several *patterns* of excretion were detected in the group.

ACKNOWLEDGMENT

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MATHEMATICAL ANALYSIS OF THE GROWTH OF MAN, WITH SPECIAL REFERENCE TO FORMOSANS[1]

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INTRODUCTION

THE growth of animals and plants consists of an increase of living substance resulting in cell division. A human ovum which has been fertilized and implanted in the uterus takes about 280 days to develop into a baby which, in turn, continues to grow after birth. It is well known that the rate of human growth is greatest during the first year of life, and that the body of the human species, like that of other animals, ceases to grow after a certain age. The weight of a human at birth doubles itself in about 5 months and trebles itself by the end of the first year.

The growth of the human body is three-dimensional, since it involves increase in the size of bones and other constituent organs. There has been a host of investigations on the growth of man which deal with the development of stature, chest girth, sitting height, span, weight and so forth. However, since the human body grows not only in one dimension, it is obvious that the growth of the body as a whole is most appropriately represented by the deevlopment of its weight, which is the resultant of the growth of the constituent organs. Therefore, body weight is the best index of growth.

With regard to the development of weight in man at different ages, there have been a great number of studies, of which the results are summarized by Baldwin ('21) and Davenport ('26A). Nevertheless, very

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[1] Aided by a grant from The China Foundation, New York, N. Y.

few authors have attempted mathematically to analyze the development of body weight from birth to maturity. Although the process of human growth is of great complexity, it is conceivable that this process follows certain natural laws which can be expressed by mathematical formulas where the amount of growth y is the function of time x. Such formulas enable one to establish the norm of human growth, to foretell with considerable certainty the quantitative results of any future observations of a similar nature, and to form some idea of the causes of deviations between the calculated and observed results.

Robertson ('15), as the result of certain theoretical considerations, found that growth in the weight of infants followed the autocatalytic equation. Lambolez ('25) obtained an exponential equation to represent the law of growth in infants. Failing to analyze the developmental curve of body weight as it is, Davenport ('26B) transformed it into a curve of annual increments of total body weight and concluded that this latter curve has two autocatalytic cycles, one being best fitted by a theoretical skew curve of Pearson's type I and the other by a normal frequency curve.

The curve of the development of weight from birth to maturity shows the same shape, roughly similar to a sigmoid, not only for Americans (Baldwin, '21 and Watson and Lowrey, '52) and Nordics (Davenport, '26A and '26B) but also for Chinese (Shirokogoroff, '25) and Japanese (Yoshinaga, '30 and Department of Physical Education, '27), except that the slope of the curve varies with race and sex. In view of the fact that no one so far has carried out any study on the physical growth of the Formosans from birth to maturity, it is of great interest first to collect as many data as possible for calculating the average weight of Formosans of both sexes at different ages, and then to analyze the weight curve to find the mathematical formulas that will serve as the norm of growth of the Formosans. Although the slope of the Formosan growth curve is different from that of others, the mathematical formulas obtained can be applied to other races when the various constants of the formulas are separately computed.

PROBLEMS FOR SOLUTION

In the mathematical analysis of the growth of Formosans, it is proposed that a number of problems which are important and interesting to various specialties of medical science and public health (physiology, anthropology, obstetrics, maternal and child health, pediatrics, school health, internal medicine, and physical education) be solved at the same time. These problems and the specialties closely related to them are summarized in table 1. Although some of these problems may be readily solved if only the mathematical formulas for the entire growth curve are obtained, still further analysis of the curve is needed in order to find the solution to the other problems.

TABLE 1

Problems to be Solved

NO.	PROBLEM
I	What course does the growth of man take in his lifetime?
II	What is the average birth weight of the Formosans?
III	What is the normal growth of Formosan infants?
IV	What is the normal growth of Formosan children of preschool age?
V	What is the normal growth of Formosan school children?
VI	What is the normal growth of Formosans from adolescence up to adulthood?
VII	What is the maximum limit of growth of the Formosans?
VIII	At what age does the adolescence of the Formosans start?
IX	At what age does the rate of adolescent growth of the Formosans reach its maximum?
X	At what age do the Formosans stop growing?

MATERIAL

Inasmuch as the physical growth of the Formosans has never been studied from birth to maturity, the weight data for the two sexes and different ages had to be collected from various sources which could be regarded as reliable. For the birth weight, the data obtained in 1942 by Wu ('49) and those in 1950 by Chiu and his coworkers ('51) have been utilized to calculate the mean. For the weight at each month of infancy, the data acquired by Wu ('49) have been used. For later years the data of the health survey collected in 1938 by the Department of Health of the Government-General of Formosa were used.[2] In all, data concerning 87,277 Formosan males and 83,376 Formosan females have been used in the present study. Table 2 presents the mean weight and the number of persons observed for each month of the first year and for each subsequent year of life.

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[2] It has been assumed that mean body weights of different persons at these various ages adequately represent the weight differences of a single group of persons successively observed at these ages. While some discrepancy might appear between these two types of observation, it would affect only the evaluation of the constants in the following formulas, and not the mode of analysis itself.

Figure 1 shows the growth curve of Formosan males and females plotted by using the average weights at different ages from table 2. Growth curves of Americans (Watson and Lowrey, '52), Nordics (Davenport, '26A and B) and Japanese (Yoshinaga, '30 and Department of Physical Education, '27) are presented in figures 2 to 4 by the use of the data derived from the respective sources cited. The dots in all these curves represent the average weights actually observed.

METHOD OF ANALYSIS

On looking at the growth curves in figures 1 through 4, it is obvious that there are more than two cycles in the course of human growth from birth to maturity, although its curve looks roughly like a sigmoid. During the first year of life, there exists a cycle of rapid growth. The curve then begins to flatten out until about 5 years of age when it rises more rapidly again. It reaches a maximum of slope in this cycle at 12 to 14 years and then gradually approaches the horizontal which indicates the state of maturity.

The mathematical analysis of human growth consists in finding out from the observed results the mathematical formulas that express certain natural laws. If the human growth curve were a straight line, then the required formula would be $y = a + bx$, which is the general equation of a straight line; the values of the constants a and b can be found by simple calculation. However, as the growth of man demonstrates a complicated curve having more than two cycles, it is quite clear that a single formula is not enough to express it. There should be as many formulas as there are cycles involved in the whole curve. It is extremely difficult to find the formula for each cycle from the shape of the curve, since it is, as a rule, impossible to tell by mere inspection whether the portion of the curve belongs to a parabola, a hyperbola, a logarithmic curve, an exponential or a trigonometric curve. The required formula must in such cases be obtained by trial. Generally one has some sort of idea as to what kind of formula to expect, and in order to test the correctness of one's expectations one can attempt to convert the curve into a straight line by means of certain artifices, such as transformation of the coordinates, use of a trial value for some constant of

TABLE 2

Observed Average Weight of Formosans

AGE IN YEARS	MALE Number of Persons Observed	 Average Weight in Kilograms	FEMALE Number of Persons Observed	 Average Weight in Kilograms
Birth	280	3.131	215	3.065
1/12	100	4.200	71	4.041
2/12	274	5.250	264	4.995
3/12	317	5.896	286	5.549
4/12	423	6.462	455	6.014
5/12	519	6.942	437	6.460
6/12	519	7.263	476	6.853
7/12	576	7.554	467	7.139
8/12	433	7.835	288	7.427
9/12	337	8.100	232	7.704
10/12	228	8.318	140	7.973
11/12	190	8.517	136	8.166
1	234	8.718	149	8.438
2	3 648	11.003	3 591	10.909
3	3 530	12.769	3 376	12.203
4	3 459	14.194	3 295	13.744
5	3 210	15.619	3 124	15.000
6	3 033	16.931	2 898	16.316
7	2 995	18.323	2 925	17.869
8	2 914	19.808	2 925	19.481
9	2 987	21.739	2 850	21.334
10	2 889	23.561	2 786	23.314
11	2 798	25.084	2 656	25.489
12	2 753	27.608	2 580	28.125
13	2 545	30.008	2 523	31.474
14	2 497	33.409	2 525	35.321
15	2 157	37.478	2 239	39.690
16	2 250	41.389	2 167	42.154
17	2 299	44.138	2 321	44.036
18	2 292	46.905	2 196	45.765
19	2 124	49.208	2 113	46.286
20	2 168	50.884	2 189	46.586
21	1 973	51.638	1 905	47.220
22	1 914	52.444	1 832	46.849
23	1 819	52.699	1 843	47.138
24	1 944	52.830	1 847	47.183
25–29	8 338	53.111	7 971	47.719
30–34	7 607	53.318	6 936	47.434
35–39	6 704	53.246	6 147	47.284
Total	87 277		83 376	

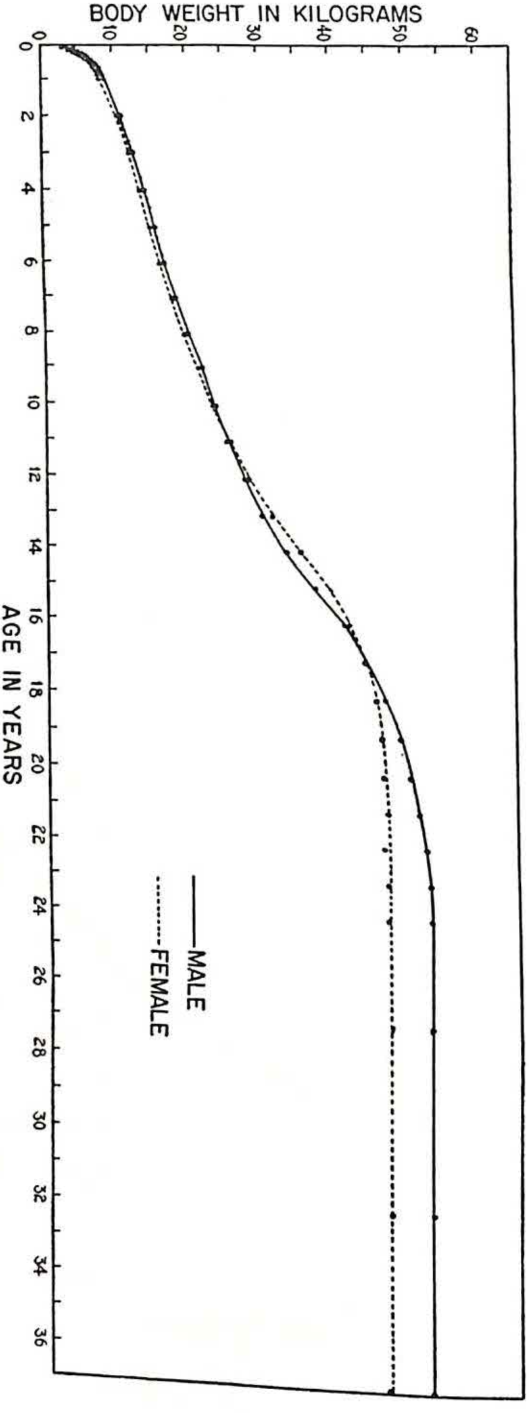

FIG. 1. GROWTH OF FORMOSANS

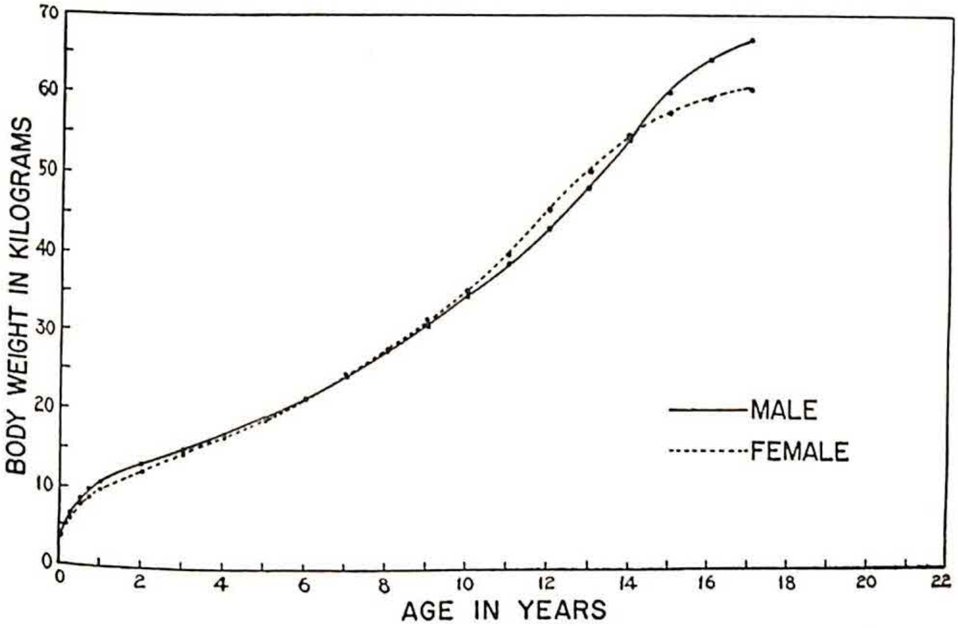

FIG. 2. GROWTH OF AMERICANS

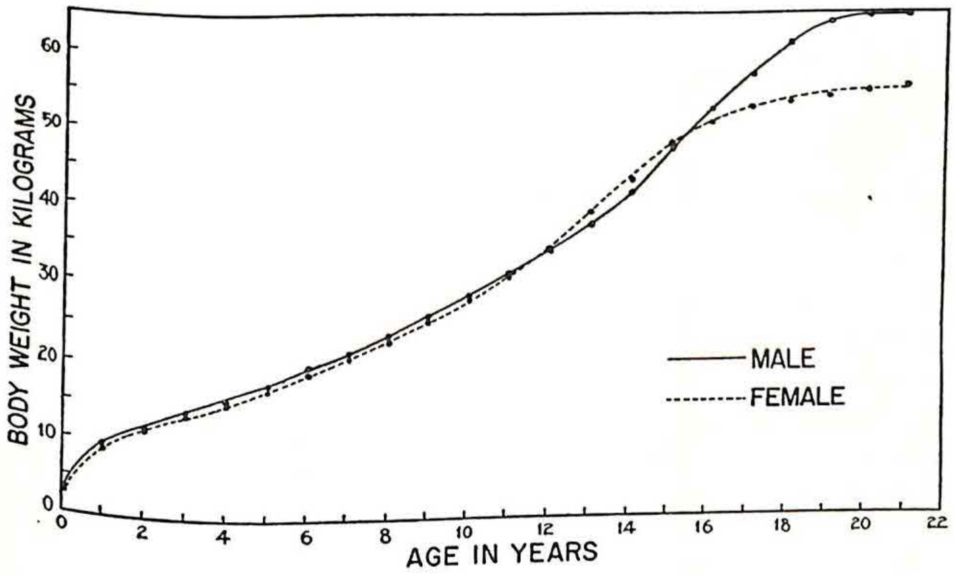

FIG. 3. GROWTH OF NORDICS

the formula, etc. If the attempt is successful, then all the constants of the formula assumed can be calculated by the method of least squares.

This is but a first approximation of the constants to the theoretical curve. It is desirable, however, to obtain the best-fitting curve by successive approximations which will correct the computed values of all the constants and thus minimize the differences between the observed points and the corresponding points on the fitted curve. If the second approximation to the best-fitting curve does not sufficiently minimize the deviations, we may proceed to the third and the fourth approximations, and so forth, by repeating the same process, till the best fit to the observed curve is finally attained.

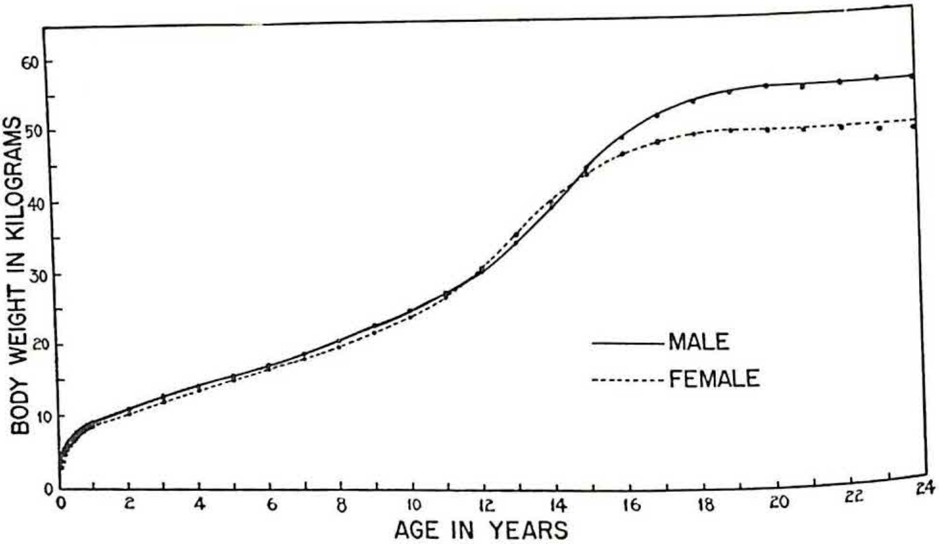

FIG. 4. GROWTH OF JAPANESE

It was found, by the procedure stated above, that the human growth curve has four cycles, of which the first and second cycles are best fitted by the catalytic equation

$$y = k - e^{a-bx}$$

where y represents weight, x denotes time and k, a and b are constants to be determined. For the Formosans, the first cycle of growth ranges from birth to 9 months, and the second cycle from 9 months to 5 years.

The third cycle of human growth, which was found to range from 5 to 13 years in Formosans, is best represented by the compound interest equation

$$y = e^{a+bx}$$

in which y and x denote weight and time respectively, and a and b are constants to be calculated.

The fourth growth cycle of the Formosans extends from 13 years till maturity, at which the body ceases to grow. The best-fitting curve to the fourth cycle of human growth is the logistic equation

$$y = d + \frac{k}{1 + e^{a+bx}}$$

where y represents weight, x denotes time, and d, k, a and b are constants to be determined. Among these four constants, d is the lower asymptote which denotes the total growth attained up to the end of the previous growth cycle, $d + k$ is the upper asymptote of the present cycle, b the inherent rate constant, and a the constant of integration dependent upon the position of the origin. The method of determining these constants is fully described in a previous paper of the writer (Quo, '50).

The constants of the above theoretical equations obtained by the first approximation should be subjected to further approximations in order to get the best fit to the observed growth curve. The observed curve of a given growth cycle may be expressed by the equation

$$y' = f(u, v, w\,; x)$$

where u, v and w are the unknown constants to be determined. Then the equation obtained from the first approximation is

$$Y_1 = f(u_1, v_1, w_1\,; x)$$

in which u_1, v_1 and w_1 are the first estimated values of the constants. Therefore

$$u = u_1 + c_1\,; \quad v = v_1 + c_2\,; \quad w = w_1 + c_3$$

where c_1, c_2 and c_3 are the correction terms that will be calculated from a subsequent approximation. By the expansion of Taylor's theorem, we get

$$\begin{aligned} f(u, v, w\,; x) = {} & f(u_1, v_1, w_1\,; x) + (u - u_1)\frac{\partial f}{\partial u_1} + (v - v_1)\frac{\partial f}{\partial v_1} \\ & + (w - w_1)\frac{\partial f}{\partial w_1} + \frac{1}{2}\Big[(u - u_1)^2\frac{\partial^2 f}{\partial u^2_1} + (v - v_1)^2\frac{\partial^2 f}{\partial v^2_1} \\ & + (w - w_1)^2\frac{\partial^2 f}{\partial w^2_1}\Big] + \Big[(v - v_1)(w - w_1)\frac{\partial^2 f}{\partial v_1 \partial w_1} \\ & + (u - u_1)(w - w_1)\frac{\partial^2 f}{\partial u_1 \partial w_1} + (u - u_1)(v - v_1)\frac{\partial^2 f}{\partial u_1 \partial v_1}\Big] \\ & + \cdots. \end{aligned}$$

Neglecting terms of higher order than the first, we have

$$y = y' - Y_1 = c_1 \frac{\partial f}{\partial u_1} + c_2 \frac{\partial f}{\partial v_1} + c_3 \frac{\partial f}{\partial w_1}$$

which is a linear expression for the correction terms. Therefore, we fit regression

$$y = y' - Y_1 = c_1 x_1 + c_2 x_2 + c_3 x_3$$

in which

$$x_1 = \frac{\partial f}{\partial u_1}, \quad x_2 = \frac{\partial f}{\partial v_1}, \quad x_3 = \frac{\partial f}{\partial w_1}.$$

The values of c_1, c_2 and c_3 are to be determined by the method of least squares.

Now for the catalytic equation, we have

$$f = k - e^{a-bx},$$

therefore

$$\frac{\partial f}{\partial k_1} = 1,$$

$$x_1 = \frac{\partial f}{\partial a_1} = - e^{a_1 - b_1 x} = -(k_1 - Y_1),$$

$$x_2 = \frac{\partial f}{\partial b_1} = x e^{a_1 - b_1 x} = x(k_1 - Y_1),$$

where a_1, b_1, k_1 and Y_1 are respectively the estimated values of a, b, k and y from the first approximation.

Let $c_0 = k_2 - k_1$; $c_1 = a_2 - a_1$; $c_2 = b_2 - b_1$, in which k_2, a_2 and b_2 are the values of the constants that will be calculated from the second approximation. Then we fit regression

$$y = y' - Y_1 = c_0 + c_1 x_1 + c_2 x_2$$

where y' denotes the observed weight. By the method of least squares, we choose c_0, c_1 and c_2 to minimize

$$f = \Sigma(y - c_0 - c_1 x_1 - c_2 x_2)^2.$$

Hence

$$\frac{\partial f}{\partial c_0} = -2\Sigma(y - c_0 - c_1 x_1 - c_2 x_2) = 0,$$

whence

$$c_0 = \bar{y} - c_1 \bar{x}_1 - c_2 \bar{x}_2,$$

in which $\bar{y}$, $\bar{x}_1$ and $\bar{x}_2$ are respectively the means of y, x_1 and x_2.

Similarly $$\frac{\partial f}{\partial c_1} = -2\sum x_1(y - c_0 - c_1x_1 - c_2x_2) = 0,$$

and $$\frac{\partial f}{\partial c_2} = -2\sum x_2(y - c_0 - c_1x_1 - c_2x_2) = 0.$$

On substitution for c_0, we get

$$\begin{aligned}\sum x_1(y - c_0 - c_1x_1 - c_2x_2) \\ &= \sum x_1(y - \bar{y} + c_1\bar{x}_1 + c_2\bar{x}_2 - c_1x_1 - c_2x_2) \\ &= \sum x_1(y - \bar{y}) - c_1\sum x_1(x_1 - \bar{x}_1) - c_2\sum x_1(x_2 - \bar{x}_2) \\ &= 0.\end{aligned}$$

Hence $$c_1\sum x_1(x_1 - \bar{x}_1) + c_2\sum x_1(x_2 - \bar{x}_2) = \sum x_1(y - \bar{y})$$

which is identical with

$$c_1\sum(x_1 - \bar{x}_1)^2 + c_2\sum(x_1 - \bar{x}_1)(x_2 - \bar{x}_2) = \sum(x_1 - \bar{x}_1)(y - \bar{y}) \qquad (A).$$

Similarly

$$\begin{aligned}\sum x_2(y - c_0 - c_1x_1 - c_2x_2) \\ &= \sum x_2(y - \bar{y}) - c_1\sum x_2(x_1 - \bar{x}_1) - c_2\sum x_2(x_2 - \bar{x}_2) \\ &= 0.\end{aligned}$$

Therefore $$c_1\sum x_2(x_1 - \bar{x}_1) + c_2\sum x_2(x_2 - \bar{x}_2) = \sum x_2(y - \bar{y})$$

which is same as

$$c_1\sum(x_1 - \bar{x}_1)(x_2 - \bar{x}_2) + c_2\sum(x_2 - \bar{x}_2)^2 = \sum(x_2 - \bar{x}_2)(y - \bar{y}) \qquad (B).$$

Equations (A) and (B) may be written

$$c_1s_{11} + c_2s_{12} = s_{1y} \qquad\qquad c_1s_{12} + c_2s_{22} = s_{2y}$$

which are the normal equations whose solution gives the values of the correction terms c_1 and c_2. The value of c_0 can be easily derived from these terms.

We may repeat this procedure, as well as those described below, for further approximations, till the best fit to the observed curve is obtained.

For the second approximation to the compound interest equation, we put

$$f = e^{a+bx}.$$

Therefore $$x_1 = \frac{\partial f}{\partial a_1} = e^{a_1+b_1x} = Y_1,$$

$$x_2 = \frac{\partial f}{\partial b_1} = xe^{a_1+b_1x} = xY_1$$

in which a_1, b_1, and Y_1 are respectively the calculated values of a, b and y from the first approximation. We fit regression

$$y = y' - Y_1 = c_1 x_1 + c_2 x_2,$$

where $c_1 = a_2 - a_1$, $c_2 = b_2 - b_1$, and y' is the observed weight. By the method of least squares, we choose c_1 and c_2 to minimize

$$f = \sum(y - c_1 x_1 - c_2 x_2)^2.$$

Hence

$$\frac{\partial f}{\partial c_1} = -2\sum x_1(y - c_1 x_1 - c_2 x_2) = 0$$

and

$$\frac{\partial f}{\partial c_2} = -2\sum x_2(y - c_1 x_1 - c_2 x_2) = 0,$$

whence

$$c_1 \sum x^2{}_1 + c_2 \sum x_1 x_2 = \sum x_1 y$$

$$c_1 \sum x_1 x_2 + c_2 \sum x^2{}_2 = \sum x_2 y,$$

which may be written

$$c_1 s_{11} + c_2 s_{12} = s_{1y} \qquad\qquad c_1 s_{12} + c_2 s_{22} = s_{2y}.$$

These are the normal equations whereby the values of the correction terms c_1 and c_2 can be easily computed.

For the second approximation to the logistic equation, we have

$$f = d + \frac{k}{1 + e^{a+bx}},$$

hence

$$x_1 = \frac{\partial f}{\partial k_1} = \frac{1}{1 + e^{a_1 + b_1 x}} = \frac{Y_1 - d_1}{k_1},$$

$$x_2 = \frac{\partial f}{\partial a_1} = \frac{-k_1 e^{a_1 + b_1 x}}{(1 + e^{a_1 + b_1 x})^2} = -\frac{(Y_1 - d_1)[k_1 - (Y_1 - d_1)]}{k_1},$$

$$x_3 = \frac{\partial f}{\partial b_1} = \frac{-x k_1 e^{a_1 + b_1 x}}{(1 + e^{a_1 + b_1 x})^2} = -\frac{x(Y_1 - d_1)[k_1 - (Y_1 - d_1)]}{k_1},$$

$$x_4 = \frac{\partial f}{\partial d_1} = 1,$$

where Y_1, d_1, k_1, a_1 and b_1 represent respectively the estimated values of y, d, k, a and b from the first approximation.

Let $c_1 = k_2 - k_1$; $c_2 = a_2 - a_1$; $c_3 = b_2 - b_1$; $c_4 = d_2 - d_1$ in which k_2, a_2, b_2 and d_2 are the values of the constants to be calculated from the second approximation. Then we fit regression

$$y = y' - Y_1 = c_1 x_1 + c_2 x_2 + c_3 x_3 + c_4 x_4,$$

where y' denotes the observed weight. The values of the four correction terms c_1, c_2, c_3 and c_4 can be calculated from the following normal equations which are obtained by the same method of least squares as already described:

$$c_1s_{11} + c_2s_{12} + c_3s_{13} + c_4s_{14} = s_{1y}$$
$$c_1s_{12} + c_2s_{22} + c_3s_{23} + c_4s_{24} = s_{2y}$$
$$c_1s_{13} + c_2s_{23} + c_3s_{33} + c_4s_{34} = s_{3y}$$
$$c_1s_{14} + c_2s_{24} + c_3s_{34} + c_4s_{44} = s_{4y}.$$

These simultaneous equations are most readily solved by the determinants given below.

$$c_1 = \frac{\begin{vmatrix} s_{1y}s_{12}s_{13}s_{14} \\ s_{2y}s_{22}s_{23}s_{24} \\ s_{3y}s_{23}s_{33}s_{34} \\ s_{4y}s_{24}s_{34}s_{44} \end{vmatrix}}{\begin{vmatrix} s_{11}s_{12}s_{13}s_{14} \\ s_{12}s_{22}s_{23}s_{24} \\ s_{13}s_{23}s_{33}s_{34} \\ s_{14}s_{24}s_{34}s_{44} \end{vmatrix}}, \quad c_2 = \frac{\begin{vmatrix} s_{11}s_{1y}s_{13}s_{14} \\ s_{12}s_{2y}s_{23}s_{24} \\ s_{13}s_{3y}s_{33}s_{34} \\ s_{14}s_{4y}s_{34}s_{44} \end{vmatrix}}{\begin{vmatrix} s_{11}s_{12}s_{13}s_{14} \\ s_{12}s_{22}s_{23}s_{24} \\ s_{13}s_{23}s_{33}s_{34} \\ s_{14}s_{24}s_{34}s_{44} \end{vmatrix}}, \quad c_3 = \frac{\begin{vmatrix} s_{11}s_{12}s_{1y}s_{14} \\ s_{12}s_{22}s_{2y}s_{24} \\ s_{13}s_{23}s_{3y}s_{34} \\ s_{14}s_{24}s_{4y}s_{44} \end{vmatrix}}{\begin{vmatrix} s_{11}s_{12}s_{13}s_{14} \\ s_{12}s_{22}s_{23}s_{24} \\ s_{13}s_{23}s_{33}s_{34} \\ s_{14}s_{24}s_{34}s_{44} \end{vmatrix}},$$

$$c_4 = \frac{\begin{vmatrix} s_{11}s_{12}s_{13}s_{1y} \\ s_{12}s_{22}s_{23}s_{2y} \\ s_{13}s_{23}s_{33}s_{3y} \\ s_{14}s_{24}s_{34}s_{4y} \end{vmatrix}}{\begin{vmatrix} s_{11}s_{12}s_{13}s_{14} \\ s_{12}s_{22}s_{23}s_{24} \\ s_{13}s_{23}s_{33}s_{34} \\ s_{14}s_{24}s_{34}s_{44} \end{vmatrix}}.$$

RESULTS

The mathematical analysis by the writer of different human weight curves revealed that human growth, regardless of race and sex, is composed of 4 cycles, namely two catalytic cycles, a compound interest and a logistic, passing from one cycle to the other without abrupt transition. The general equation for each cycle is the same for all races and both sexes, but the constants of the equation vary due to the fact that the slope of the portion of the curve differs with sex and race. Slight variations in the duration of growth cycles are observed among different races.

The durations and the final equations for the 4 cycles of the theoretical growth curve of Formosans are shown below. These equations enable one to predict the normal average weight for the two sexes at any age from birth to maturity.

First Cycle: Catalytic Growth

General Equation:

$$y = k - e^{a-bx}$$

$$\text{or} \quad y = k - Ae^{-bx}$$

Formosans:

Period: from birth to 9 months

Equation:

Male

$$y = 8.8 - e^{1.7243-0.2172x} \tag{1}$$

$$\text{or} \quad y = 8.8 - 5.6088e^{-0.2172x} \tag{2}$$

Female

$$y = 8.5 - e^{1.6870-0.1988x} \tag{3}$$

$$\text{or} \quad y = 8.5 - 5.4034e^{-0.1988x} \tag{4}$$

Second Cycle: Catalytic Growth

General Equation:

$$y = k - e^{a-bx}$$

$$\text{or} \quad y = k - Ae^{-bx}$$

Formosans:

Period: from 9 months to 5 years

Equation:

Male

$$y = 21.5 - e^{2.7390-0.1913x} \tag{5}$$

$$\text{or} \quad y = 21.5 - 15.4722e^{-0.1913x} \tag{6}$$

Female

$$y = 20.5 - e^{2.6873-0.1958x} \tag{7}$$

$$\text{or} \quad y = 20.5 - 14.6928e^{-0.1958x} \tag{8}$$

Third Cycle: Compound Interest Growth

General Equation:

$$y = e^{a+bx}$$

$$\text{or} \quad y = Ae^{bx}$$

Formosans:

Period: from 5 years to 13 years

Equation:

Male $$y = e^{2.34034+0.08135x} \tag{9}$$

or $$y = 10.3851e^{0.08135x} \tag{10}$$

Female $$y = e^{2.24202+0.09146x} \tag{11}$$

or $$y = 9.4126e^{0.09146x} \tag{12}$$

Fourth Cycle: Logistic Growth

General Equation:

$$y = d + \frac{k}{1 + e^{a+bx}}$$

or $$y = d + \frac{k}{1 + Ae^{bx}}$$

Formosans:

Period: from 13 years onwards

Equation:

Male $$y = 19 + \frac{34.5}{1 + e^{1.21071-0.44726x}} \tag{13}$$

or $$y = 19 + \frac{34.5}{1 + 3.3559e^{-0.44726x}} \tag{14}$$

Female $$y = 22 + \frac{25.5}{1 + e^{1.06866-0.59474x}} \tag{15}$$

or $$y = 22 + \frac{25.5}{1 + 2.9115e^{-0.59474x}} \tag{16}$$

Note: $y =$ body weight in kilograms
$x =$ age in months for equations (1) to (4)
$x =$ age in years for equations (5) to (12)
$x =$ age in years $-$ 12 for equations (13) to (16).

The normal average weight of the Formosans at any time of life can be obtained by solving the above equations. Table 3 presents the normal average weight, both actually observed and theoretically calculated, of Formosans at each age. In the light of the small deviations of the computed values from the observed, it is clear that equations (1) through (16) excellently fit the 4 growth cycles of Formosans.

TABLE 3

Average Weight of Formosans as Observed and as Theoretically Calculated

AGE IN YEARS	MALE WEIGHT IN KILOGRAMS Observed	Calculated	Deviations (Obs.-Calc.)	FEMALE WEIGHT IN KILOGRAMS Observed	Calculated	Deviations (Obs.-Calc.)
Birth	3.131	3.191	-0.060	3.065	3.097	-0.032
1/12	4.200	4.286	-0.086	4.041	4.071	-0.030
2/12	5.250	5.167	0.083	4.995	4.870	0.125
3/12	5.896	5.877	0.019	5.549	5.524	0.025
4/12	6.462	6.447	0.015	6.014	6.061	-0.047
5/12	6.942	6.907	0.035	6.460	6.501	-0.041
6/12	7.263	7.276	-0.013	6.853	6.861	-0.008
7/12	7.554	7.574	-0.020	7.139	7.157	-0.018
8/12	7.835	7.813	0.022	7.427	7.399	0.028
9/12	8.100	8.096	0.004	7.704	7.597	0.107
10/12	8.318	8.308	0.010	7.973	8.019	-0.046
11/12	8.517	8.518	-0.001	8.166	8.223	-0.057
1	8.718	8.722	-0.004	8.438	8.421	0.017
2	11.003	10.947	0.056	10.909	10.569	0.340
3	12.769	12.784	-0.015	12.203	12.335	-0.132
4	14.194	14.302	-0.108	13.744	13.788	-0.044
5	15.619	15.597	0.022	15.000	14.981	0.019
6	16.931	16.919	0.012	16.316	16.293	0.023
7	18.323	18.353	-0.030	17.869	17.854	0.015
8	19.808	19.908	-0.100	19.481	19.564	-0.083
9	21.739	21.595	0.144	21.334	21.437	-0.103
10	23.561	23.426	0.135	23.314	23.490	-0.176
11	25.084	25.411	-0.327	25.489	25.740	-0.251
12	27.608	27.565	0.043	28.125	28.205	-0.080
13	30.008	29.967	0.041	31.474	31.784	-0.310
14	33.409	33.545	-0.136	35.321	35.519	-0.198
15	37.478	37.379	0.099	39.690	39.127	0.563
16	41.389	41.103	0.286	42.154	42.083	0.071
17	44.138	44.394	-0.256	44.036	44.197	-0.161
18	46.905	47.065	-0.160	45.765	45.565	0.200
19	49.208	49.089	0.119	46.286	46.395	-0.109
20	50.884	50.543	0.341	46.586	46.878	-0.292
21	51.638	51.549	0.089	47.220	47.153	0.067
22	52.444	52.227	0.217	46.849	47.307	-0.458
23	52.699	52.675	0.024	47.138	47.393	-0.255
24	52.830	52.968	-0.138	47.183	47.441	-0.258
25–29	53.111	53.359	-0.248	47.719	47.490	0.229
30–34	53.318	53.485	-0.167	47.434	47.499	-0.065
35–39	53.246	53.498	-0.252	47.284	47.500	-0.216

DISCUSSION

Growth consists of an increase in the number of tissue cells as a result of cell division. Hence it follows that growth takes place according to geometric progression in some form or other. Food material, ingested and assimilated in the body, is absorbed into the blood and carried to the various tissues of the body where it is partly used up, and partly transformed into the components of the tissue cells, such as nuclear material and cytoplasm, which are utilized in cell division to build up new cells. This biochemical transformation of food material is caused by the catalytic action of enzymes, which have vitamines as active components and are regulated by hormones.

In chemical reaction by catalysis, the reaction velocity $\frac{dy}{dx}$ at any instant is proportional to the amount of material present at that moment, i. e.,

$$\frac{dy}{dx} = b\,(k - y)$$

where y represents the amount of material transformed at time x, k denotes the original amount of material, b is the proportionality constant and $k - y$ equals the amount of material which remains untransformed at time x. This differential equation may be written

$$\frac{dy}{k - y} = b\,dx.$$

Integrating,

$$\int \frac{dy}{k - y} = b \int dx,$$

we get

$$-\log_e(k - y) + c = bx + c',$$

or

$$\log_e(k - y) = -bx + c - c',$$

where c and c' are constants of integration.

Put

$$a = c - c',$$

then

$$\log_e(k - y) = a - bx.$$

Hence

$$y = k - e^{a-bx},$$

or

$$y = k - Ae^{-bx} \qquad (A = e^{a}),$$

both equations expressing the two catalytic cycles of human growth.

Since growth is due to geometric increase in the number of tissue cells, it can also be considered from another aspect of the chemical reaction which occurs in the tissue to synthesize nuclear material and cytoplasm. The reaction velocity $\frac{dy}{dx}$ at any instant x is also proportional to the amount of the product, y, formed by the reaction at that moment. If this proportionality is converted into an equality by insertion of a proportionality constant b, we obtain the differential equation for the rate of formation of the product by the reaction, namely,

$$\frac{dy}{dx} = by.$$

Separating the variables,

$$\frac{dy}{y} = b dx,$$

and integrating,

$$\int \frac{dy}{y} = b \int dx,$$

we get

$$\log_e y + c = bx + c'.$$

Putting

$$a = c' - c,$$

we have

$$\log_e y = a + bx.$$

Therefore

$$y = e^{a+bx},$$

or

$$y = Ae^{bx} \qquad (A = e^a),$$

which are the equations expressing the compound interest law in Nature. The third cycle of human growth follows this law.

The logistic equation, discovered by Verhulst (1838, 1845, 1847) and independently by Pearl and Reed ('20, '22, '23), gives an S-shaped curve with an upper and a lower asymptote and describes accurately the growth trend of human populations which cannot surpass its upper limit in a growth cycle. The fourth cycle of human growth is best expressed by the logistic equation. It is of considerable interest that the growth of human individuals from adolescence to maturity follows the same logistic law as the growth of human populations.

The maximum limit to the growth in man is represented by the upper asymptote of the logistic curve, $d + k$, of which d is the lower asymptote of the fourth cycle and k corresponds to the total amount of growth attained in the same cycle. Therefore, the maximum limit to the growth of the Formosans for each sex is

Male $d + k = 19 + 34.5 = 53.5$ Kilograms,

Female $d + k = 22 + 25.5 = 47.5$ Kilograms.

Since the logistic growth cycle extends from adolescence to adulthood, we can calculate the age of maximum rate of adolescent growth by finding the coordinates of the point where the rate of growth is a maximum. This point is the point of inflection of the logistic curve. After that point is passed, the rate of growth declines progressively, till finally the curve stretches along horizontally in close approach to the upper asymptote, over which the body cannot grow. Now the logistic equation to the fourth cycle of human growth is

$$y = d + \frac{k}{1 + e^{a+bx}}.$$

We put

$$z = y - d = \frac{k}{1 + e^{a+bx}},$$

then

$$z' = \frac{dz}{dx} = \frac{-kbe^{a+bx}}{(1 + e^{a+bx})^2}$$

$$= \frac{kb - kb - kbe^{a+bx}}{(1 + e^{a+bx})^2}$$

$$= \frac{bz^2 - kbz}{k},$$

which is the equation to the first derivative curve. Therefore

$$z'' = \frac{1}{k}(2bz - kb)z' = 0.$$

At the point of inflection evidently z' is not equal to zero, hence

$$z = \frac{k}{2},$$

and

$$y = \frac{k}{2} + d.$$

Therefore

$$1 + e^{a+bx} = 2,$$

and

$$x = -\frac{a}{b}.$$

Accordingly, the age at which the maximum rate of adolescent growth occurs in the Formosan male is

$$x + 12 = -\frac{a}{b} + 12 = \frac{1.21071}{0.44726} + 12 = 14.707$$
$$= 14 \text{ years and } 8.5 \text{ months.}$$

Similarly, the age of maximum rate of adolescent growth for the Formosan female is

$$x + 12 = -\frac{a}{b} + 12 = \frac{1.06866}{0.59474} + 12 = 13.797$$
$$= 13 \text{ years and } 10 \text{ months.}$$

With a view to comparing the growth velocities at different ages, the curves of annual increments in the body weight of the Formosans are illustrated in figure 5.

After birth the velocity of growth begins to diminish at first rapidly and then gradually until between 4 and 5 years, both sexes always running roughly parallel with each other. It then rises by degrees, in such a fashion that the female exceeds the male all the time. At between 11 and 12 years in the female and between 12 and 13 years in the male, the velocity of growth rises abruptly and reaches a maximum at between 13 and 14 years in the female and between 14 and 15 years in the male, though the latter maximum is higher than the former. The point of maximum growth velocity corresponds to the point of inflection of the logistic cycle. It is conceivable that the starting point of this abrupt rise in growth velocity indicates the beginning of adolescence. The age of maximum rate of adolescent growth for each sex which has been theoretically calculated, can also be estimated graphically.

After this peak is reached, the velocity of growth diminishes at first slowly, then rapidly, and again slowly, till it practically reaches zero which indicates maturity or adulthood. After the age of maximum rate of adolescent growth is passed, the males always weigh more than the females. It is obvious from figure 5 that the age at which growth stops is 26 years for Formosan females and 31 years for Formosan males. Further gain in weight after these years may be considered as due solely to the deposition of fat, which does not involve increase in the number of tissue cells resulting from cell division. The curves in figure 5 make it clear that females mature earlier than males.

It is well known that the endocrine glands play a vital role in growth by a specific effect of their hormones on growing tissue and by their influence on the body's metabolism. The anterior pituitary secretes a specific growth hormone whose principal actions are accelera-

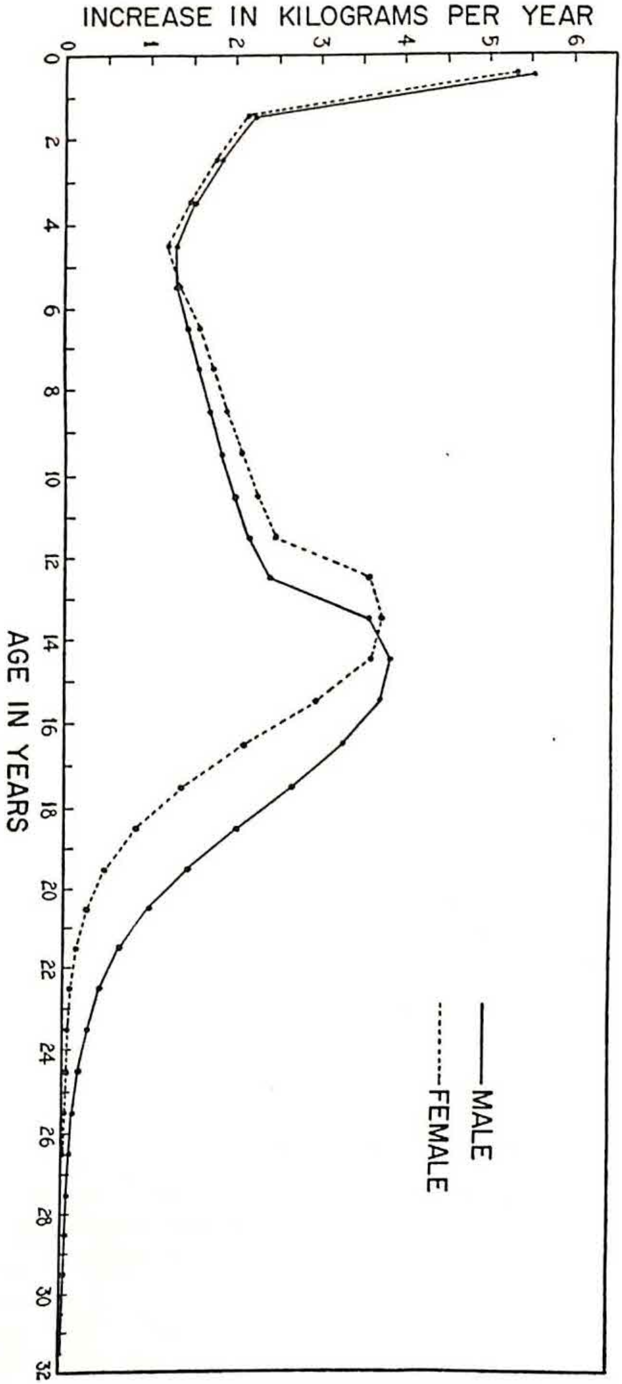

FIG. 5. ANNUAL INCREMENTS IN BODY WEIGHT OF FORMOSANS

tion of bone growth and tissue building. Less directly the gland influences growth by the action of its hormones on other glands of internal secretion. The thyrotropic hormone of the anterior pituitary regulates the secretion of thyroxine of the thyroid gland, which is probably second only to the pituitary in relative importance in its influence on growth and development. A normally functioning thyroid promotes skeletal growth, increases the metabolic rate and promotes sexual maturation.

The gonadotropic hormones secreted by the anterior pituitary cause the ovarian cycle and the secretion of ovarian hormones in the female, and bring about the spermatogenesis as well as the secretion of testis hormone in the male. The gonads are also necessary for proper development of the body. The importance of the parathyroid glands to normal growth and development can be appreciated from the fact that these glands are responsible for normal bone development.

It is well established (DeLee and Greenhill, '48) that the functions of the maternal anterior pituitary and thyroid glands are increased during pregnancy and gradually return to normal after childbirth. The fetus which has been growing at an accelerated rate under the influence of the various growth-inciting hormones from the mother's blood, slows down the velocity of its growth after birth (see figure 5), presumably for the reason that these hormones come to the infant only insufficiently from the milk. As time goes by, the child's own endocrine glands gradually increase their functions, so that the velocity of growth rises correspondingly.

When the function of the anterior pituitary and thyroid glands is increased so greatly as to stimulate the sex glands, the velocity of growth is sharply accelerated. This is the onset of adolescence which is to be followed before long by puberty or sexual maturation. As can be seen from figure 5, the age of onset of adolescence is between 11 and 12 years in the Formosan female and between 12 and 13 years in the Formosan male.

Puberty begins when the sex glands become mature as a result of continuous stimulation by the anterior pituitary and thyroid hormones. The first menstruation is generally recognized as an objective indicator of puberty in the female, while in the male there is no marked sign, except for the onset of nocturnal emissions which does not necessarily coincide with the onset of puberty. According to S. R. Ko ('33) and K. E. Ko ('33), the average age of the first menstruation in the For-

TABLE 4

Solution of the Problems Proposed

PROBLEM NO.	SOLUTION			
I	First Cycle: Catalytic Growth Period for Formosans: from birth to 9 months			
	Second Cycle: Catalytic Growth Period for Formosans; from 9 months to 5 years			
	Third Cycle: Compound Interest Growth Period for Formosans; from 5 years to 13 years			
	Fourth Cycle: Logistic Growth Period for Formosans; from 13 years onwards			
II	Birth Weight:	Male	3.191 Kilograms	(see table 3)
		Female	3.097 Kilograms	
III	see table 3			
IV				
V				
VI				
VII	Maximum Limit of Growth:	Male	53.5 Kilograms	
		Female	47.5 Kilograms	
VIII	Age of Onset of Adolescence:	Male	between 12 and 13 years	(see figure 5)
		Female	between 11 and 12 years	
IX	Age of Maximum Rate of Adolescent Growth:	Male	14 years and 8.5 months	(see figure 5)
		Female	13 years and 10 months	
X	Age at which Growth stops:	Male	31 years	(see figure 5)
		Female	26 years	

mosan female is 14 years to 14 years and 8 months. This is nearly the age of maximum rate of adolescent growth in the Formosan female that has been mentioned previously. It would seem that at the onset of puberty the velocity of the adolescent growth is at its maximum. In other words, the advent of pubescence is preceded by an acceleration, and followed by a retardation of growth in weight in the two sexes.

The problems proposed in table 1 are already solved by the results and discussion in the present study; the solutions to these problems are summarized in table 4.

SUMMARY

In order to solve problems which are of practical importance in various branches of medical science, a mathematical analysis of the human growth in weight has been carried out with special reference to the growth of the Formosans. Data about 87,277 Formosan males and 83,376 Formosan females, collected from 1938 to 1950, have been used in the present investigation.

It has been found that the growth of man has 4 cycles from birth to maturity. Both the first and the second growth cycles obey the law of catalytic reaction, except for the difference in rate of growth between the two cycles. The third growth cycle is ruled by the law of compound interest in Nature, whilst the fourth growth cycle follows the logistic law that describes the growth of human populations. These 4 cycles pass from one to the other with gradual transition.

The mathematical procedure for the analysis of the human growth curve has been thoroughly described, and the periods and equations of the 4 cycles for the two sexes of the Formosans have been calculated with accuracy.

The body weights at different ages of the Formosan male and female computed from the equations obtained were found to yield excellent agreement with the observed data from birth to maturity.

The ages for the onset of adolescence and the maximum rate of adolescent growth among Formosans of both sexes, as well as for physical maturity, have been determined; and the maximum limits of growth that Formosan males and females may reach in their lifetime, have also been calculated.

The changes in the growth velocity throughout the whole period of body development have been discussed from the endocrinological point of view.

Appreciation is expressed to Professor William G. Cochran, School of Hygiene and Public Health, Johns Hopkins University, for his suggestions and criticisms in the preparation of this paper.

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